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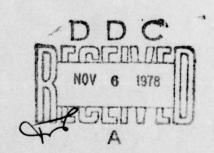
A FEASIBILITY STUDY OF RESPONSE TECHNIQUES FOR DISCHARGES OF HAZARDOUS CHEMICALS THAT SINK

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U. S. Army Engineer Waterways Experiment Station P. O. Box 631 Vicksburg, Miss. 39180



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PREFACE

The feasibility study reported herein was conducted under Military Interdepartmental Purchase Request number Z-70099-7-71258-A by personnel from the Environmental Laboratory (EL) of the U. S. Army Engineer Waterways Experiment Station (WES).

MAJ Terry D. Hand, CE, and Mr. Alfred W. Ford were the principal authors and overall editors of the report. Contributing authors were: Dr. Philip G. Malone (Chapters 2 and 3) and Messrs. Douglas W. Thompson (Chapter 6) and Richard B. Mercer (Chapter 2). Significant technical input and invaluable advice were rendered by Dr. William D. Barnard, 1LT Robert E. Buhts, CE, and Mr. Raymond C. Solomon. The study was conducted under the direct supervision of Mr. Norman R. Francingues, project manager and Chief, Treatment Processes Research Branch, EL, and under the general guidance of Mr. Andrew J. Green, Chief, Environmental Engineering Division, EL, and Dr. John Harrison, Chief, EL.

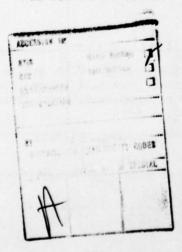
Special recognition is extended to the personnel of JBF Scientific Corporation, specifically Mr. Jaret C. Johnson, project manager, Drs. Robert B. Pojasek and Robert L. Lancione, chemists, and Mr. James E. Soden, ocean engineer, who researched and furnished to the WES the majority of the contents of Chapters 5 and 6 and Appendices D, E, and F.

Appendix A was written and generously provided by Mr. James C. Willmann, U. S. Environmental Protection Agency, Region X, Seattle.

The diligent and patient efforts of Ms. Cherry Shaler and Ms. Rosie Lott, typists, and Mr. Jack Dildine, graphics coordinator, are gratefully acknowledged, as is the detailed editing assistance provided by Ms. Jamie Leach.

The appreciation of the authors is also extended to Mr. John R. Sinclair, U. S. Coast Guard, who as project monitor provided balanced measures of guidance, latitude, and patience without which this study could not have been successfully completed.

During the period of this study (March - October 1977) the Commander and Director of the WES was Colonel John L. Cannon, CE; Technical Director was Mr. F. R. Brown.



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TABLE OF CONTENTS

			Page
1.0	TMTD	ODUCTION	1
1.0	1.1	BACKGROUND	1
	1.2	OBJECTIVES	2
		SCOPE	3
		APPROACH	4
	1 5	PRESENTATION OF STUDY RESULTS	4
	1.5	RESENTATION OF STUDY RESULTS	
2.0	CHEM	ICAL CONSIDERATIONS	7
2.0	2.1	CHEMICAL BACKGROUND	7
	2.2	INTERACTION OF CHEMICALS THAT SINK WITH SEDIMENT	26
	2.3		28
	2.5	RATIONALE FOR RESTONSE RECOMMENDATIONS	20
3.0	SPIL	L SCENARIOS	31
3.0	3.1	INTRODUCTION	31
	3.2		31
	3.2	DEVELOPMENT OF SCHWARTOS	-
4.0	DRFD	GING TECHNIQUES	38
7.0	4.1	INTRODUCTION	38
		DREDGING PRACTICE AND EQUIPMENT	39
	4.3	LOCATION AND AVAILABILITY OF DREDGES IN THE U. S	67
			70
		ENVIRONMENTAL CONSIDERATIONS	72
			75
	4.6	DREDGE SYSTEM EVALUATION	15
5.0	RIIRT	AL TECHNIQUES	86
3.0	5.1	INTRODUCTION	86
	5.2	CHEMICALS AMENABLE TO BURIAL	87
	5.3	IDENTIFICATION AND CHARACTERIZATION OF BURIAL	0,
	3.5	MATERIALS	90
	5.4	EMPLACEMENT AND EROSION CONTROL MEASURES	111
	5.5	BURIAL SYSTEM EVALUATION	157
	3.5	BURIAL BIBLE EVALUATION	13,
6.0	OTHE	R HIGH POTENTIAL TECHNIQUES	161
	6.1	INTRODUCTION	161
	6.2	CHEMICAL COMPATABILITY	162
	6.3	CONTAINMENT	162
	6.4	COVERS	170
	6.5	SORBENTS	184
	6.6	CHEMICAL TREATMENT	190
	6.7	BIODEGRADATION	205
	6.8	DISPERSION	207
	6.9	OTHER RESPONSE TECHNIQUES EVALUATION	213
	0.9	OTHER RESPONSE TECHNIQUES EVALUATION	213

TABLE OF CONTENTS (Concluded)

		Page
7.1 SUN	AND CONCLUSIONS AND RECOMMENDED RESEARCH PLAN . MMARY AND CONCLUSIONS	219 219 223
REFERENCES		232
APPENDIX A:	PCB TRANSFORMER SPILL, SEATTLE, WASHINGTON	A-1
APPENDIX B:	PNEUMA SYSTEM	B-1
APPENDIX C:	DREDGE DIRECTORY	C-1
APPENDIX D:	LITERATURE REVIEW OF BURIAL AND BURIAL MATERIALS	D-1
APPENDIX E:	SCOUR AND RESUSPENSION OF NATURAL SEDIMENTS - A DETAILED DISCUSSION	E-1
APPENDIX F:	SPECIAL PURPOSE COMMERCIAL CLAYS - COST AND AVAILABILITY	F-1
	LIST OF FIGURES	
Figure No.		Page
4-1	DIPPER DREDGE	45
4-2	BUCKET LADDER	45
4-3	CLAMSHELL DREDGE	46
4-4	PLAIN SUCTION DREDGE	46
4-5	DUSTPAN DREDGE	49
4-6	CUTTERHEAD SUCTION DREDGE	49
4-7	HOPPER DREDGE	52
4-8	"PNEUMA" DREDGE	52
		57
4-9	MUDCAT DREDGE	3/

LIST OF FIGURES (Continued)

Figure No.		Page
4-10	AVERAGE FEDERAL DREDGING COSTS	65
5-1	HOPPER DREDGE PIPING SCHEMATIC	116
5-2	PROPOSED SPRAY BAR ARRANGEMENT	119
5-3	OPEN-PIPE DISCHARGE BARGE	124
5-4	DIFFUSER DISCHARGE BARGE CONCEPT	127
5-5	FULL-SCALE DIFFUSER CONCEPT	128
5-6	PROPOSED PUMP-DOWN BARGE	132
5-7	DECK ARRANGEMENT FOR BARGE-MOUNTED APPARATUS FOR PREFORM FILM OVERLAY SYSTEM	136
5-8	OVERALL FILM OVERLAY EQUIPMENT ARRANGEMENT	137
5-9	CONSTRUCTION BY DEEP CHEMICAL MIXING (DCM) METHOD	139
5-10	CONSTRUCTION OF A TYPICAL SILT CURTAIN SECTION .	143
5-11	TYPICAL SILT CURTAIN CONFIGURATION	145
5-12	MECHANISMS INVOLVED IN TURBIDITY CONTROL BY A SILT CURTAIN	146
5-13	PROPOSED DIKE UNDERWATER DISPOSAL TECHNIQUE	148
6-1	DEPLOYED HAZARDOUS MATERIAL BARRIER	164
6-2	BARRIER DEPLOYMENT PROCEDURE	165
6-3	POSSIBLE GROUTING ARRANGEMENT	173
6-4	TWO-PHASE IN SITU FILM DISPENSING HEAD	178
6-5	EXPERIMENTAL OXYGEN INJECTION SYSTEM	198
6-6	CLEARING OIL FROM UNDER PIERS WITH BOOM AND WATER JETS	211
A-1	PCR SPILL LOCATION (13 SEPTEMBER 1974)	A-2

LIST OF FIGURES (Concluded)

Figure No.		Page
A-2	PRECLEANUP - PCB SEDIMENT CONCENTRATIONS (18 SEPTEMBER 1974)	A-4
A-3	DISPOSITION OF SPILL RECOVERY EQUIPMENT	A-8
A-4	POSTCLEANUP - PCB SEDIMENT CONCENTRATIONS (4 NOVEMBER 1974)	A-10
A-5	PCB SEDIMENT CONCENTRATIONS (2 JUNE 1975)	A-11
A-6	PCB SEDIMENT CONCENTRATIONS (18 JUNE 1975)	A-13
A-7	PCB SEDIMENT CONCENTRATIONS (APRIL 1976)	A-17
B-1	THREE SCOOP "PNEUMA" SYSTEM	B-2
B-2	SINGLE SCOOP "PNEUMA" SYSTEM	B-3
B-3	"PNEUMA" MANIFOLD SYSTEM	B-5
E-1	EROSION-DEPOSITION CRITERIA FOR UNIFORM PARTICLES	E-2
E-2	EROSION VELOCITY VERSUS WATER CONTENT FOR A PARTICULAR SEDIMENT	E-4
	LIST OF TABLES	
Table No.		Page
2-1	SOLID CHEMICALS	9
2-2	LIQUID CHEMICALS	16
3-1	SPILL SCENARIOS	32
3-2	SPILL SIZE CLASSIFICATION USED IN THIS STUDY	34
3-3	INCIDENTS OF SPILLS OF SUBSTANCES OTHER THAN OIL	35
3-4	SITE-SPECIFIC ENVIRONMENTAL FACTORS RANKED AS TO IMPACT ON RESPONSE TO SINKER SPILL IN INDICATED	
	SETTING	36

LIST OF TABLES (Continued)

Table No.		Page
4-1	SUCTION DREDGE PIPELINE DISCHARGE RATES, CUBIC YARDS PER HOUR	50
4-2	SPECIFICATIONS FOR TYPICAL DREDGES OF VARIOUS TYPES	51
4-3	PERTINENT CHARACTERISTICS OF CORPS OF ENGINEERS HOPPER DREDGES	54
4-4	SUMMARY OF DREDGE OPERATING CHARACTERISTICS	59
4-5	COMPARATIVE DREDGING COSTS	64
4-6	TOTAL CORPS FLEET INVENTORY: REGIONAL DISTRIBU-	69
4-7	POTENTIAL EFFECTS OF DREDGING OPERATION	71
4-8	DREDGE EVALUATION MATRIX SPILL SCENARIO: LAND AND NONNAVIGABLE WATERS - ALL SPILL SIZES	76
4-9	DREDGE EVALUATION MATRIX SPILL SCENARIO: RIVER - ALL SPILL SIZES	77
4-10	DREDGE EVALUATION MATRIX SPILL SCENARIO: PORTS AND HARBORS - ALL SPILL SIZES	78
4-11	DREDGE EVALUATION MATRIX SPILL SCENARIO: OPEN WATERS - ALL SPILL SIZES	79
5-1	GENERALIZED LIST - INERT COVERING MATERIALS	92
5-2	TENDENCIES OF NATURAL INERT SEDIMENTS TO ERODE	95
5-3	ACTIVE COVERING MATERIALS	102
5-4	SELECTED ACTIVE COVERING AGENTS: COST, APPLICATIONS, AND SPECIFIC GRAVITY	104
5-5	ELECTROMAGNETIC NAVIGATION SYSTEMS	153
5-6	COMPARISON OF DISTANCE MEASURING TECHNIQUES	155
5-7	DISTANCE MEASURING EQUIPMENT FOR STATIC APPLICATIONS	156

LIST OF TABLES (Concluded)

Table No.		Page
5-8	BURIAL EMPLACEMENT SYSTEM EVALUATION MATRIX, ALL SPILL SCENARIOS	159
5-9	RECOMMENDED COVERING MATERIALS FOR SPECIFIC CHEMICALS	160
6-1	CANDIDATES FOR NEUTRALIZATION	202
6-2	CHRIS CHEMICALS SUBJECT TO DISPERSION	208
6-3	RESPONSES OTHER THAN DREDGING APPROPRIATE TO FUNCTIONAL CLASSES OF CHEMICALS	215
6-4	RESPONSES, OTHER THAN DREDGING, APPROPRIATE TO VARIOUS SPILL SCENARIOS	217
A-1	INITIAL TREATMENT PLANT RESULTS	A-7
A-2	OPERATIONAL COSTS	A-18
B-1	PNEUMA PUMP SIZES	B-4
B-2	MANIFOLD SIZES	B-6

1.0 INTRODUCTION

1.1 BACKGROUND

The Federal Water Pollution Control Act Amendments of 1972 (PL 92-500), 50 U.S.C. 191 (the Magnuson Act), and 14 U.S.C. 88 require the United States Coast Guard* to respond to hazardous chemical spills in U.S. waters. Because of the disparity between the Coast Guard's statutory obligation to respond to such spills and the current undeveloped state of spill response and pollution control technology, the Coast Guard has undertaken a research program to bring its capabilities in line with its responsibilities.

In the early stages of this research program, the Coast Guard compiled a list of 900 hazardous chemicals and identified from these a list of 400 which are transported in significant quantities on water and are therefore of immediate concern. These chemicals were classified as floaters, sinkers, vapors, and those that mix or dissolve. Subsequent research has generally focused on one or more of these categories, recognizing that greatly differing responses are appropriate to each.

Sinking hazardous chemicals, the subject of this study, have been defined by the Coast Guard to be those chemicals (or their reaction products) that are more dense than water and relatively insoluble in water (those for which a saturated solution is 10% or less by weight at 20° C). Of the 400 chemicals listed and subsequently described in the Chemical Hazards Response Information System (CHRIS) 1 , 70 have been designated sinkers. They include inorganic and organic compounds that are solid or liquid at normal temperatures, have a diverse range of physical and chemical properties, and present a variety of associated hazards.

The greatest difficulty in ameliorating or otherwise dealing with spills of chemicals that sink stems from the fact that the material is resting on or moving along the bottom of the body of water, physically separated by the water column from any surface-borne means of detection

^{*} Hereafter referred to as Coast Guard.

and response. The fact that the material is relatively insoluble and may be in a separately identifiable phase from the surrounding water can be both a benefit and a problem. On the one hand, the material will tend not to disperse as rapidly throughout the surrounding water as would a soluble material, and therefore its immediate effects on aquatic life and human use of the water would tend to be less acute. On the other hand, the insoluble hazardous materials on the bottom will not be rapidly diluted to harmless levels, but may persist in the sediment at dangerous concentrations for long periods of time. In many cases gradual dissolution of a relatively insoluble toxic material into the water around it could continue to contaminate the water body for many years.

There are essentially three possible courses of action in dealing with a hazardous material on the bottom: 1) allow it to remain there, taking no action; 2) recover the material; or 3) make the material less hazardous by physically or chemically isolating it where it lies. In previous studies for the Coast Guard² and the U. S. Environmental Protection Agency (EPA)³ dredging (removal) and burial (isolation) have been suggested as the responses that have some expectation of success. Dredging to remove hazardous materials or contaminated sediments has thus far been used in a limited number of actual spills and has received some attention in small-scale field demonstrations sponsored by the EPA. Burial of othemical spills, on the other hand, has received little attention and no actual use or field testing.

The overall goal of this study is to provide an engineering assessment of the feasibility of dredging, burial, and other possible options in various response situations. Each evaluation must take into consideration the physical setting in which the spill occurs as well as the type and amount of hazardous material involved.

1.2 OBJECTIVES

The objective of this study was to determine the feasibility of using dredging, burial, or other response techniques to ameliorate the adverse effects resulting from discharges of hazardous chemicals that sink. This included an assessment of the state of the art in responding

to hazardous chemicals deposited under water.

Additionally, based on the findings, recommendations will be made for research and development where significant advances are possible in developing the Coast Guard's response capability against hazardous sinking chemicals.

1.3 SCOPE

The major effort of this investigation was concentrated on response options that now are possible or would be possible with minor modification of existing equipment or techniques. Untested techniques requiring concepts or equipment not yet developed are included, but not treated as high potential response options. There is little precedent or information directly related to responding to sinking hazardous chemical spills, and since this study involved no experimental testing or field or laboratory evaluations, all recommendations are necessarily based on engineering and scientific evaluation, and, in some cases, extrapolation of existing data and literature.

Detecting, locating, marking, and monitoring of the boundaries of the spill zone on the bottom are not within the prescribed scope of this study, but are nevertheless immensely important in any effective response effort. The assessments of response techniques presented herein assume that the nature, quantity, areal coverage, and concentration of the spilled material on the bottom are known.

The storage, transportation, treatment (decontamination), and disposal of contaminated dredged material could be a controlling factor in determining the proper course of action. Again, this study does not include direct consideration of the problems associated with the handling and disposition of the material once it is recovered, except where such considerations affect the recovery operation itself.

To aid in dealing with unusual circumstances surrounding chemical spills, discussions of the important characteristics of the various group of hazardous materials that sink and of environmental effects of major response systems have been included.

1.4 APPROACH

This study involved the accomplishment of four major tasks:

- o Task I. To develop a set of spill scenarios (combination of spill sizes and environmental settings) that will lend itself to the practical assessment of the various possible responses to spills of hazardous materials that sink.
- o Task II. To determine the feasibility of using currently available, or modified, dredging methods and equipment for removal of hazardous chemicals or contaminated sediments from the bottoms of bodies of water.
- o Task III. To determine the feasibility of burying spilled hazardous chemicals on the bottom as a means of ameliorating their adverse effects. This would involve assessing both potential burial materials and their emplacement methods.
- o Task IV. To identify and determine the practical feasibility of any other potential amelioration measures not included in the dredging and burial categories, including chemical treatment, adsorption, dispersion, and containment.

1.5 PRESENTATION OF STUDY RESULTS

This study was approached in the four distinct task areas delineated above (Spill Scenarios, Dredging, Burial, and Other Techniques). The report is similarly organized around chapters corresponding to each area. Although each chapter stands alone to some extent, there is a great deal of interdependence and commonality in the considerations involved. Moreover, any realistic assessment of an actual spill situation will simultaneously involve consideration of the spill scenario and all possible classes of response, including combinations.

For purposes of a useful report, initial consideration required a broad overview of the physical, chemical, and toxicological characteristics of the 70 chemicals under consideration. In Chapter 2 this is accomplished along with a rationale for selecting a response appropriate to the chemicals' properties. Some of this discussion is repeated in

more specific terms in the dredging, burial, and other techniques chapters.

In Chapter 3 a matrix of 12 spill scenarios is established which consists of each combination of four environmental settings versus three spill sizes. This produces an arbitrary, but useful, framework in which response techniques can be discussed and evaluated.

Chapter 4 deals with dredging and the recovery of hazardous materials from the bottoms of waterways. A great deal of technical and nontechnical information is presented to familarize the reader with the diverse and highly specialized field of dredging and to provide a basis for assessing the feasibility of dredging for hazardous chemicals. The feasibility assessments themselves are presented in the form of four matrices in which the major dredge types are numerically evaluated in terms of their potential for use in a hazardous material recovery role in each of the four environmental settings established in Chapter 3. It must be recognized that numerical ratings such as those presented are extremely subjective. In an untested application of a procedure that resists generalization to begin with, such evaluations must be considered qualitative. Nonetheless, the matrices are useful in the sense that they identify high and low potential systems in various situations and show likely problem areas with specific dredge types in specific scenarios.

The burial option is addressed in Chapter 5. Though burial will seldom be the first choice in ameliorating the effects of a spill, in some cases it may be selected by default. Detailed consideration is given in this chapter to selected burial materials to cover selected spilled chemicals (those for which burial holds the most promise). The discussion includes both inert materials and chemicals to bury/neutralize the spilled chemical. Further consideration of the latter is provided in Chapter 6, "Other High Potential Techniques," but in a more general application to all 70 chemicals. Also critical to any consideration of burial of a spill is the method of placing the cover. A number of techniques considered to hold promise are discussed in depth, and in the final section, numerically evaluated as to their probable utility in

each spill scenario. Again, these ratings are subjective and should not be patently taken out of context.

Chapter 6, "Other High Potential Techniques," deals with all aspects of amelioration of a sinker spill except recovery. This includes: containment; further considerations of burial, particularly with novel materials and techniques; sorbents; in situ chemical treatment (overlapping somewhat with consideration of active cover materials in Chapter 5); biodegradation; and dispersion. Each selected response method is discussed in detail with consideration given to applicable spilled chemicals, techniques for applying or accomplishing the procedure (tried and untried), applicability to various spill scenarios, and cost considerations. For the diverse and specialized techniques addressed in this chapter, a numerical evaluation of feasibility potential was not considered possible, even in a qualitative sense. However, a series of tables are provided at the end of the chapter which summarize the techniques discussed and relate them to appropriate classes of chemicals and spill settings.

The major conclusions that can be reached about each type of response are given in Chapter 7, along with a suggested program of research, development, and demonstration that would progressively enhance the Coast Guard's capability to effectively respond to sinker spills.

2.0 CHEMICAL CONSIDERATIONS

2.1 CHEMICAL BACKGROUND

The following information is presented to introduce the discussion of recovery and/or isolation of the 70 hazardous chemicals under consideration in this study and to familiarize the reader with their important physical and chemical characteristics. This discussion is not intended to supplant the CHRIS manuals or other handbooks which cover the properties of industrial chemicals such as the Merck Index and fire underwriters manuals.

To simplify the discussion, the 70 chemical substances are arranged in groups according to similarities in physical and chemical characteristics. A major division is made according to the physical state of the substances as they are normally shipped, i.e., solid or liquid. Further subdivisions are made based on their chemical composition as follows:

- Inorganics Substances that do not contain carbon atoms as the major constituent of the molecule.
- II. Organics Substances that do contain carbon atoms as the major constituent of the molecule.
 - A. Halogenated Organic compounds that also contain any of the halogens, i.e., fluorine, chlorine, iodine, or bromine (especially chlorine or bromine).
 - B. Nonhalogenated All other organic compounds.

It will be noted that this categorization of the 70 chemicals differs from the system proposed by Lyman et al. 2 and further developed by Bauer et al. 4 in previous studies for the Coast Guard. Though these two references represent valuable pioneering work, it was felt that the four categories of sinkers they propose (IIIA, Solids; IIIB, Inorganic Liquids; IIIC, Halogenated Organic Liquids; and IIID, Aromatic Organic Liquids) and the representative hazardous chemicals (RHC) they select were not suited to the purposes of this study in which an attempt is made to consider each chemical and a number of specific responses.

Each substance is listed in Table 2-1, Solid Chemicals, or in Table 2-2, Liquid Chemicals, along with a qualitative indication of its toxicity, flammability, reactivity with water, solubility in water, persistence in the aquatic environment, potential for bioaccumulation, and a very brief comment on any specific hazards relating to its recovery or burial and a recommended response. A generalized summary, by group, of these properties and specific hazards is presented in the following paragraphs.

2.1.1 Solids

Solid inorganic substances vary greatly and no generalized statement can be made about this group as a whole. The hazards involved with these substances are principally related to their reactivity with water or air. Phosphorus, especially in the form of white phosphorus, represents an unusual problem because of its extreme reactivity with air. It can combust spontaneously if exposed to air, yet its extreme toxicity requires that it not be allowed to remain in the aquatic environment. FMC and Monsanto, the principal manufacturers of phosphorus, have developed response measures in case of spills and should be consulted immediately in the event of a spill.

Other materials in this group show reactivity with water. These are largely materials that are anhydrous (lacking water). Among these are aluminum chloride, calcium carbide, calcium oxide (unslaked lime), and lithium aluminum hydride. These substances decompose on contact with water to form explosive (e.g. calcium carbide) and/or toxic (e.g. aluminum chloride) gases, or react to take up water in a reaction that generates large amounts of heat (e.g. calcium oxide). In the event of a spill involving hazardous inorganic solids, any evidence of reactivity should be noted immediately and all gaseous reaction products bubbling to the surface should be assumed to be hazardous or explosive until shown to be otherwise. Reactive solids tend to form coatings of reaction products which may slow or even temporarily halt the reaction until the material is disturbed or the coating is removed. Once a reaction producing explosive or toxic gas has been observed, protective measures

Table 2-1 Solid Chemicals

Recommended Responses		Disperse in water or flush away solid, neutralize with limestone or lime slurry if necessary.
Unique Requirements Relating to Personnel Safety and Equipment Maintenance		Reacts with water to form highly toxic and corrosive (acid) hydrogen chloride gas. Highly flammable hydrogen gas may also be produced on contact with metal. Protective clothing and mask should be worn. Bare metal will be heavily corroded.
Bio-8 accumu- lation		g.
Persistence f Solu- In Aquatic bility Environment		z
Solu- bility		AN .
Flam-C Reactivity ^d Solu- In Aquatic mability With Water bility Environment		μ
Flam-c mability		z
Tox-b		z
DOT ^a Code		ACI.
Chemical	I. Inorganics	Aluminium Chloride ACL

(Continued)

Persistence estimates are based on chemical and biological degradability data from many sources, including: manufacturers test data, EPA 011 and Hazardous Materials Technical Assistance Data System (OHM-TADS), and knowledge of chemistry. Legend is keyed as follows: N = not persistent, material reacts with water to form nonhazardous or much less hazardous products; L = 95% degradation within six months; M = 95% degradation within 10 years; E = does not degrade. In cases where substance breaks down but products are equally harmful, rating includes persistence of products.

Bioaccumulation estimates are provided by Allan R. Isensee, USDA, Beltsville, Md., and are based on actual measurements, partition coefficients, or chemical similarities. Legend is keyed as follows: N not used: L = bioaccumulates to less than 100 times water concentration; H = bioaccumulates to more than 1000 times water concentration; H = bioaccumulates to more than 1000 times water concentration; E not used.

Table 2-1 (Continued)
Solid Chemicals

Chemical	DOT a	Tox-b	Flam-C mability	Reactivity d	Solu- bility	Persistence In Aquatic Environment	Bio-8 accumu- lation	Unique Requirements Relating to Personnel Safety and Equipment Maintenance	Recommended Responses
Aluminium Fluoride ALF	ALF	x:	z	z	×	ω	z	Goggles and mask to protect against particulate material. Aquatic solution is toxic.	Because of toxicity in water, removal preferred with burial second-best alternative.
Barium Carbonate	BRC	×	z	z		œ	¥	Solution is toxic.	Will react with sulfate to form inert, insoluble barium sulfate. If not re- acted with sulfate, ma- terial should be removed.
Calcium Carbide	8		z	ы	Ž	z	ê	Reacts with water to form highly flammable and explosive acetylene gas. Acetylene gas should not be confined or brought in contact with copper or brass. Forms strongly alkaline calcium hydroxide during reaction.	Will react completely to produce calcium hydroxide, which should be removed or buried.
Calcium Fluoride	3		z	z	J	ш	ı,	Protection against inhaling particulates required.	Remove or bury; presence is danger to aquatic organisms and local water supplies.
Calcium Hydroxide	8	×	z	z	H	H	1	Goggles and dust-proof mask required. Solution is corrosive (strongly alkaline).	Remove, bury, or disperse.

(Continued)

Table 2-1 (Continued)
Solid Chemicals

Chemical	DOT	Tox-	Flam-c mability	Reactivity With Water	Solu- bility	Persistence In Aquatic Environment	Bio-8 accumu- lation	Unique Requirements Relating to Personnel Safety and Equipment Maintenance	Recommended Responses
Calcium Oxide	9	×	z	×	ğ	=	È	Generates heat when in contact with water. Gloves, goggles, and respirator should be worn. Solution is corrosive (strongly alkaline).	Will react completely to form calcium hydroxide, which should be removed, buried, or dispersed.
Lead Arsenate	3	æ	z	z	z	ш	1	Poisonous if swallowed. Respirator to prevent inhalation of particulates required. Protective clothing necessary.	Soluble in acid conditions. Removal is best course, followed by burial with a basic material to prevent dissolution and isolate.
Lithium Aluminium Nydride	3	m	ω	ω	£	z	È	Produces highly flammable hydrogen gas on contact with water. Full face shield and rubberized gloves should be worn. Solution is corrosive (alkaline).	Will react completely to produce lithium hydroxide and aluminum hydroxide, which should be removed, buried, or dispersed.
Phosphorous, Red	8		=	z	z	E .		Heat may cause reversion to highly toxic and spontaneously flammable yellow phosphorous. Dust mask, rubber gloves, safety glasses, and rubber shoes are required.	Toxic, should be removed. Requires specialized handling by manufacturers (FMC Corporation and Monsanto). If burial is attempted, an active material or oxidizer should be used to convert from

(Continued)

Table 2-1 (Continued)
Solid Chemicals

Chemical	DOT	Tox-b	Flam-c mability	Reactivity With Water	Solu- bility	Persistence In Aquatic Environment	accumu- lation	Unique Requirements Relating to Personnel Safety and Equipment Maintenance	Recommended Responses
Phosphorous, White	Mdd	æ	ш	z	z	I		Ignites spontaneously in air. Heavy rubber gloves and face shield should be worn.	Toxic, should be removed. Requires specialized handling by manufacturers (FMC Corporation and Monsanto).
Sulfur (See Liquid Chemicals, Table 2.2)	Chemic	als, Ta	ble 2.2)						
II. Organics									
A. Halogenated									
Aldrin	Q P	ш	z	2	٦.	×	x	Extremely toxic if ingested or if skin is exposed. Wear goggles, mask, and protective clothing.	Toxic, should be removed.
Benzene Hexachloride	ВНС	æ	z	z		x	Ŧ	Wear goggles and self-contained breathing apparatus.	Toxic, should be removed.
DDT	DDT	×	×	z	Z	×	I	Protective clothing required.	Toxic, should be removed.
p-Dichlorobenzene	DBP	×	×	z		×	×	Face mask with organic vapor can- ister, eye protection and protec- tive clothing should be worn.	Toxic, should be removed.
2,4-Dichlorophenol	DCP	×	×	z	×	×	×	Use of respirator, rubber gloves, and goggles required.	Toxic, should be removed.
						(Found found)	1		

Table 2-1 (Continued)
Solid Chemicals

Chemical	Code	Tox-b	Flam-C mability	Reactivity With Water	Solu- bility	Persistence In Aquatic Environment	accumu- lation	Unique Requirements Relating to Personnel Safety and Equipment Maintenance	Recommended Responses
Pentachlorophenol	5	×	z	z	×	œ	1	Respirator, goggles, and protective clothing should be worn.	Toxic, should be removed.
Toxaphene	2	ш	z	×		æ	=	Toxic gases produced when heated. Wear chemical respirator, rubber gloves, and goggles or face shield.	Toxic, should be removed.
Trichlorophenol	HAI	×	z	z	1	×	×	Dust is an irritant. Protective clothing and mask for toxic dust should be worn.	Toxic, should be removed.
B. Nonhalogenated									
Asphalt	ASP	1	1	z	z	.	7	Protective clothing and goggles should be worn when handling hot material. May foul dredging equipment.	Should be buried or removed.
Asphalt:Roofers Flux	ARE		1	z	z	=	ı	Wear protective clothing and eye protection. May foul dredging equipment.	Should be buried or removed.
Asphalt:Straight Run Residue	ASR	1		z	z	=	'n	Goggles and protetive clothing required. May foul dredging equipment.	Should be buried or removed.

(Continued) For explanation of symbols, see legend and explanatory notes on first page of Table 2-1.

Table 2-1 (Continued)
Solid Chemicals

Chemical	DOT a	Tox-b	Flam-c mability	Reactivity With Water	Solu- bility	Persistence In Aquatic Environment	Bio-8 accumu- lation	Unique Requirements Relating to Personnel Safety and Equipment Maintenance	Recommended Responses
Benzoic Acid	BZA	×	×	z	×		1	Eye protection and protective clothing should be worn.	Moderately toxic, should be removed, if possible. Dispersal may be accept- able.
Bisphenol A	BPA	×	×	z	1		,	Dust mask, protective clothing, and Toxic, should be removed. goggles required.	Toxic, should be removed.
Carbaryl	CBY	æ	z	z	1	×	1	Avoid contact with solid or solutions.	Toxic, should be removed.
Dibenzoyl Peroxide DPO	DPO	x	ш	z	*	×	д	Explosion sensitive to shock, heat, and friction. Do not contaminate with combustible material or other easily oxidized substances. Goggles, face shield, and rubber gloves should be worn.	Extremely dangerous, should be removed, will require special handling. Consult Pennwalt Corp., Witco Chemical Corp.
2,4-Dinitroaniline DNT	TNO	#		z	z	=	u	Toxic if inhaled, ingested, or in contact with skin. Breathing apparatus, goggles, rubber gloves plastic coat, and protective shoes required. Avoid heating or confining in unvented system, can detonate.	Toxic, should be removed, may require special handling. Consult American Aniline Products or Marrin Marietta Corporation.

(Continued)

Table 2-1 (Concluded)
Solid Chemicals

Chemical	Code	Tox-b	Flam-C mability	Reactivity With Water	Solu- bility	Persistence In Aquatic Environment	Bio-8 accumu- lation	Unique Requirements Relating to Personnel Safety and Equipment Maintenance	Recommended Responses
2,4-Dinitrophenol	ANG	æ	×	z	ii.	æ	_	May explode if heated when in confined space. Wear breathing apparatus, rubber gloves and clothing, goggles, and protective shoes.	Toxic, should be removed. May require special handling. Consult American Aniline Products or Martin Marietta Corporation.
Dipheny laethane Diisocyanate	20	×	.1	1	z	E	1	Slow reaction with water forms carbon dioxide. Respirator, glowes, goggles and protective clothing recommended.	Toxic material and reaction products, should be removed.
Naphthalene	Ę	×	×	z	×	pr.	x	Organic vapor canister respirator, goggles, rubber gloves, and protective clothing and boots should be worn. May foul dredging equipment. May be shipped in molten condition.	Toxic, especially to aquatic life, should be removed.
Phthalic Anhydride PAN	PAN	×	1		z	,	ı	Nonhazardous reaction with water forming phthalic acid. Protective clothing and boots, goggles, organic vapor respirator, and gloves required.	Mcderately toxic, should be removed, if possible. Dispersal may be accept- able.

For explanation of symbols, see legend and explanatory notes on first page of Table 2-1.

Table 2-2 Liquid Chemicals

Chemical	Code	Tox-b	DOT Tox-b Flam-C Code icity mability	Reactivity Solu- With Water bility		Persistence In Aquatic Environment	Bio-5 accumu- lation	Unique Requirements Relating to Personnel Safety and Equipment Mintenance	Recommended Response
I. Inorganics									
Browine	BRX		z	z	æ	ш	.1	Highly cortosive, may cause fire if in contact with combustibles. Re- acts violently with aluminum. Rubber clothing, goggles, face shield, and self-contained breathing unit required. Will corrode iron, steel, stainless steel, and copper.	Toxic, may be flushed away because of high solubility or may be removed. Epoxy or Teflon-lined equipment should be used to avoid corrosion damage.
Mercury	MCR.	×	×	×	×	Kaj	æ	Avoid direct contact with skin. Use chemical cartridge respirator for vapors.	Toxic, nondegradable, and bioaccumulating; should be removed.
Sulfur (Molten)	X			ı	×	×	4	Highly toxic hydrogen sulfide gas may accumulate in closed areas. Safety goggles, respirator, and heat-resistant clothing required. If recovering sulfur, take precautions for hydrogen sulfide gas. Solidified sulfur may foul or clox dredging equipment.	Should be removed or buried; ultimate removal rec- ommended due to production of toxic gases or acid.

For explanation of symbols, see legend and explanatory notes on first page of Table 2-1.

Table 2-2 (Continued) Liquid Chemicals

Chemical	Code	Tox-b	Flam-C mability	Reactivity With Water	Solu- bility	Persistence In Aquatic Environment	Bio-e accumu- lation	Unique Requirements Relating to Personnel Safety and Equipment Maintenance	Recommended Response
II. Organics									
A. Halogenated									
Benzoyl Chloride	BZC	×	×		×	1	1	Reacts with water to produce hydro- chloric acid fumes. Protective clothing, goggles, gloves, and full face acid gas and organic	Toxic, should be removed, if possible. Otherwise neutralize with lime and disperse.
								vapor respirator required. Will corrode dredging equipment.	
chloride	CBT	×	z	z	1	æ	1	Organic vapor canister, full face mask, protective clothing, and rubber gloves should be worn.	Toxic, should be removed.
Chlorobenzene	88	×	æ	z	1	æ		Toxic gases produced in fire, heavy Toxic, should be removed. vapor can travel considerable distance to flame. Protective clothing, organic vapor and acid gas respirator and goggles re- quired.	Toxic, should be removed.
Chloroform	9	×	z	z	×		.1	Goggles and full face mask or self- contained breathing unit required depending on concentrations en- countered.	Toxic, should be removed.

Table 2-2 (Continued) Liquid Chemicals

o-Dichlorobenzene	Code	Tox-b	Flam-c mability	Reactivity With Water	Solu- bility	Persistence In Aquatic Environment	Bio-8 accumu- lation	Unique Requirements Relating to Personnel Safety and Equipment Maintenance	Recommended Response
	080	=		z	1	æ	×	Toxic gases produced in fire. Organic vapor and acid gas respirator, goggles, rubber apron, gloves, and boots should be worn.	Toxic, should be removed.
Dichloromethane	8	x	1	z	=	×		Organic vapor mask, eye protection, and protective clothing required.	Toxic, should be removed, but due to high solu- bility dispersal may be only recourse.
Dichloropropane	990	×	=	2	×	×	-1	Flashback along vapor trail may occur. Toxic gases produced in fire. Rubber gloves and boots, goggles and protective clothing required. In confined areas air supply necessary.	Toxic, should be removed.
Dichloropropene	DPR	æ	æ	z	z	æ	,	Toxic gases produced in fire. Full face organic vapor mask required.	Toxic, should be removed.
Epichlorohydrin	EPC	×	æ	×	ı	z		Nonhazardous reaction with water forming hydrochloric acid. Organic canister mask, gloves, and goggles should be worn.	Toxic, should be removed if it can be identified; however, due to reactiv- ity and solubility, dis- persal may be most practi- cal response in a water spill.

(Continued)

Table 2-2 (Continued)
Liquid Chemicals

The state of the s

Chemical	DOT	Tox-b	Flam- ^c mability	Reactivity With Water	Solu-e bility	Persistence In Aquatic Environment	Bio-8 accumu- lation	Unique Requirements Relating to Personnel Safety and Equipment Maintenance	Recommended Response
Ethylene Dibromide	EDB	=	z	z	×	æ	1	Toxic vapors, Wear canister-type mask, neoprene gloves, and goggles.	Toxic, should be removed.
Ethylene Dichloride EDC	EDC	×	ш	z	×	æ		Flashback along vapor trail may occur. Gases generated in fires are toxic. Protective clothing, goggles and gas mask or self-contained breathing unit required depending on concentration.	Toxic, should be removed; possibly disperse.
Polychlorinated Biphenyl	PCB	×	J	z	z	W	z	Gloves and protective clothing recommended.	Toxic, nondegradable, and highly bioaccumulating; absolutely should be removed.
Tetrachloroethylene TTE	e TTE	×	z	z	a.	æ	,	Wear goggles and plastic gloves. When high vapor concentrations are present wear canister or air supply mask.	Toxic, should be removed.
Trichloroethane	TCE	×	ı		1	x	٦	Reacts slowly with water forming hydrochloric acid. Organic vapor and acid gas canister mask; neoprene gloves, boots, and clothing; and goggles required. May corrode dredging equipment, esp. aluminum.	Toxic, should be removed.
Trichloroethylene	TCL	×		z	×	ш	יי	Vapor irritating, organic vapor and acid gas canister mask required. Gloves and goggles should be worn.	Toxic, should be removed.

For explanation of symbols, see legend and explanatory notes on first page of Table 2-1.

(Continued)

Table 2-2 (Continued) Liquid Chemicals

Trichlorofluoro- methane Vinylidene Chloride VCI M Monhalogenated Acetophenone		mability With Water	Solu- bility	In Aquatic Environment	accumu- lation	to Personnel Safety and Equipment Maintenance	Recommended Response
VCI genated	z	z	X:	ж	1	Air line respirator, rubber gloves and goggles required. Will evaporate rapidly in air, contact with skin may cause frostbite.	Toxic, should be brought to surface and allowed to evaporate in safe area.
ACP.	ш	z	×	x		Toxic gases generated in fires. Flashback along vapor trail may occur. Wear canister mask, goggles, rubber gloves, and boots. Polymerization may occur if exposed to sunlight, air, copper, aluminum, or heat.	Toxic, should be removed. Due to tendency to polymerize, this material may clog dredging equipment.
ACP							
	×	2	×	u	n	Protect eyes and skin from direct contact.	Slightly toxic, should be removed, if possible. Dispersion may be an acceptable solution.
Aniline ANL H	1	z	ж	x	1	Wear organic vapor respirator, goggles, rubber gloves, and boots.	Toxic, should be removed.

(Continued)

Table 2-2 (Continued) Liquid Chemicals

Chemical	Code		Tox-b Flam-c	Reactivity With Water	Solu-e	Persistence In Aquatic Environment	Bio-8 accumu- lation	Unique Requirements Relating to Personnel Safety and Equipment Maintenance	Recommended Response
Benzaldehyde	BZD	×	×	×	×		1	Goggles and protective clothing should be worn.	Toxic, should be removed, but due to high solubil- ity and degradability material may not remain
									sufficiently long to dredge; dispersion may be only recourse.
Camphor 011	8	1	×	z	Z	×	2	Protect eyes, avoid contact with liquid. Camphor oil may float.	Somewhat toxic, should be removed. If floating, material should be dealt with as oil.
Carbolic 011	9	æ	J	z	m	×	-1	May explode if mixed with air. Air mask in closed areas, rubber gloves, protective clothing, and full face shield required.	Toxic, should be removed.
Carbon Bisulfide	8	m	ш	2	×	×		Flashback along vapor trail may occur. Supplied air respiratory equipment with full face mask, goggles, and protective clothing required.	Toxic, should be removed.
Cresols	SE	=	1	z		×	2	Toxic flammable gases produced in fire. Wear organic vapor canister mask, rubber gloves, apron and boots, goggles and face shield.	Toxic, should be removed. Speed is essential since material is quite soluble. Material may float and be handled as oil.

(Continued)

Table 2-2 (Continued) Liquid Chemicals

Chemical	Code	Tox-	Flam-c mability	Reactivity With Water	Solu- bility	Persistence In Aquatic Environment	Bio-R accumu- lation	Unique Requirements Relating to Personnel Safety and Equipment Maintenance	Recommended Response
Dibutyl Phthalate	DPA		1	z	z		\$	Protect eyes.	Somewhat toxic, should pro- bably be removed, but is a possible candidate for containment and burial.
Dimethyl Sulfate	DSF	ш	,	1	ns e	x	٦	Nonhazardous reaction with water producing acid. Wear goggles; rubber gloves, suit and boots; and self-contained breathing apparatus. Corrosive to dredging equipment.	Toxic, should be removed.
Dowthern	ELG	1	٦.	Z	1	×	ı	Wear eye protection.	Somewhat toxic and aesthetically objectionable, should be removed.
Furfural	FFA	=	×	Z	x	æ	u	Protect exposed skin and eyes.	Toxic, should be removed; however, high solubility may present problems.
Glycidyl Methacrylate	8	z	H	z	z	E	¥.	Polyethylene coated apron and gloves, and goggles should be worn. Heat, peroxides, and caustics cause polymerization. May clog equipment, May float.	Toxic, should be removed.

(Continued)

Table 2-2 (Concluded) Liquid Chemicals

Chemical	DOT	Tox-bicity	Flam-c mability	Reactivity With Water	Solu- bility	Persistence In Aquatic Environment	Bio-8 accumu- lation	Unique Requirements Relating to Personnel Safety and Equipment Maintenance	Recommended Response
Malathion	MLT	w	7	z	1	1	1	Extremely toxic to aquatic fauna. Wear self-contained breathing apparatus and rubber clothing.	Toxic, should be removed.
Methyl Parathion	Ě	ш	×				1	Extremely toxic to both humans and aquatic fauna. Toxic gases produced in fire. Rubber gloves and boots, protective clothing, goggles and an approved mask or respirator should be worn.	Toxic, should be removed.
Motor Fuel Anti-Knock Compounds Contain- ing Lead Alkyls M	nock in- MFA	æ	×	Z	1	æ	1	Poisonous vapors produced in fires. Fresh air mask, gloves, goggles,	Toxic, should be removed.
Nitrobenzene	8 EN	ш	×	z	×	æ	2	Toxic vapors generated when heated. Rapidly absorbed through skin. Organic vapor respirator, rubber gloves, and goggles necessary.	Toxic, should be removed.
Terraethyl Lead	且	=	æ	z	z	z	1	Toxic gases produced in fires. Air line mask, neoprene gloves, rubber boots, goggles, and light-colored clothing should be worn. Reacts with rust and some metals.	Toxic, should be removed.
Tetramethyl Lead	星	æ	æ	Z	1	æ	-1	May explode in fire. Wear air line mask, goggles, rubber boots, neoprene gloves, and light-colored clothing.	Toxic, should be removed.
Tricresyl Phosphate	10	×	,	z		ж	AN.	Toxic if ingested, especially when ortho isomer is present. Protect eyes.	Toxic, should be removed.

For explanation of symbols, see legend and explanatory notes on first page of Table 2-1.

should be continued because any disturbance of the material will accelerate the chemical reaction. For example, calcium carbide reacts rapidly with water to produce the explosive and toxic gas acetylene, but during the reaction a coating of calcium hydroxide forms on the granules of carbide slowing or stopping the gas production. Any agitation or disturbance of the spilled material can accelerate or reinitiate the reaction by removing or breaking the calcium hydroxide coating.

Several of the inorganic solid substances included in the list of 70 chemicals are relatively toxic, notably barium carbonate and lead arsenate. These materials require protection against ingestion, inhalation, and skin exposure, but are relatively inert and easily contained if recovered.

Halogenated organic solids typically are highly toxic if ingested or inhaled and require precautions. They are only moderately flammable or nonflammable, but often release poisonous gases when exposed to heat or flame. Generally, they are relatively nonreactive and are only slightly soluble in water.

The principal problems related to recovery or burial of solid halogenated organic compounds are related to their toxicity. Many of these materials are potent pesticides; thus skin contact, inhalation, and ingestion are to be rigorously avoided. In addition, many halogenated (especially chlorinated) organics are known carcinogens.

Nonhalogenated organic solids covered in this report (with the exception of 2,4-dinitroaniline and 2,4-dinitrophenol, which are highly toxic) are only moderately to slightly toxic. Their flammability is low to moderate with the notable exception of dibenzoyl peroxide which is extremely flammable and explosion-sensitive. This group is also nonreactive with water and only very slightly soluble in water.

2.1.2 Liquids

<u>Inorganic liquids</u> are variable in toxicity, but are only slightly flammable or nonflammable. All are nonreactive with water and except for liquid bromine, which is moderately soluble, all are virtually insoluble in water.

Liquid bromine is extremely volatile and corrosive. It is similar in its chemical properties to chlorine. Like chlorine, bromine vapor is corrosive and toxic; thus, handling material contaminated with bromine will require protective clothing and corrosion-resistant equipment. The relatively high solubility of bromine may result in the loss of a great deal of this material into the surrounding water, causing an extremely adverse environmental impact.

Mercury presents problems during recovery because care must be taken to avoid inhaling its vapor. The vapor pressure of mercury is such that in air at normal temperatures a cloud of vapor surrounds the liquid metal. At higher temperatures, especially in closed spaces, the concentration of mercury vapor can quickly reach toxic levels. Special monitoring equipment using the ultra-violet light absorbing properties of mercury vapor can be used to monitor the concentration of mercury in the air during recovery operations. Most State industrial hygiene agencies have portable mercury vapor monitoring equipment and trained personnel available. Mercury poisoning can be detected in personnel exposed to this material through routine urinalysis. Mercury in the aquatic environment is especially hazardous because it is accumulated as it passes up the food chain, often appearing in harmful levels in the top carnivores (in aquatic systems, these usually are desirable game fish).

Liquid sulfur is a relatively inert material that solidifies upon contact with water. Consequently it is considered a minor hazard. In aquatic biological systems it may be slowly oxidized to sulfate and can produce acid conditions in the sediment. The solidified mass of amorphous sulfur may be difficult to recover with conventional dredging equipment.

All liquid halogenated organic compounds treated here are moderately toxic except for epichlorohydrin and ethylene dibromide which are highly toxic. Many of these compounds vaporize easily and breathing apparatus may be required to handle them. Although flammability varies considerably within this group, with equal numbers of highly flammable and nonflammable substances and a few moderately to slightly flammable

compounds, almost all produce toxic gases when burned or heated. Reactivity with water is nonhazardous or nonexistent except for benzoyl chloride and trichloroethane which react slowly with water to produce hydrochloric acid. Liquid, halogenated organic compounds themselves are only slightly soluble in water. Many chlorinated hydrocarbons are classed as cancer-producing substances in humans, so contact with these materials should be minimized.

Nonhalogenated organic liquids classed as sinking chemicals are generally highly toxic. Most of these compounds are moderately flammable (highly flammable exceptions are carbon bisulfide, methyl parathion, tetraethyl lead, and tetramethyl lead). These compounds are either nonreactive with water or produce nonhazardous products in reactions with water. Solubility is variable. In general, recovery of these compounds will require protective clothing and masks or portable breathing equipment. For personnel working with lead-organic spills, routine measurements of lead levels in blood may be a useful precaution.

2.2 INTERACTION OF CHEMICALS THAT SINK WITH SEDIMENT

The list of 70 chemicals that are the subject of this study contains a number of materials that will interact with the sediments found on the bottoms of most waterways. In some cases, interactions help in reducing the hazard or in immobilizing the spilled material to facilitate its removal. The major types of interaction are: (a) dilution, (b) adsorption, (c) chemical reactions (including neutralization), and (d) reactions involving biological systems.

Dilution of the spilled chemical can be both a benefit and a hindrance to potential response procedures. Dilution benefits recovery operations in that it reduces the concentration of toxic corrosive materials that must be handled by the response team. In most cases, this substantially reduces the risk to personnel and adverse effects on equipment. However, dilution increases the volume of material that must be moved, stored, and/or treated.

Adsorption includes any physical or chemical process that attaches a liquid contaminant to a solid sediment phase. This action often

immobilizes the contaminant and permits recovery of the adsorbed liquid phase. The ability or inability of a particular material to be adsorbed on sediment depends on its solubility, molecular size, tendency to ionize, and vapor pressure. The character of the sediment has an effect on the amount and type of material adsorbed. In a typical sediment sample the most actively adsorbing part of the sediment is the finegrained fraction, consisting primarily of clay minerals and organic material. The coarse (sand-sized and greater) fraction of sediment usually consists of quartz and rock fragments--material with much less favorable adsorption characteristics. Most immobilization due to adsorption will occur in fine-grained, as opposed to coarse-grained, sediments. Adsorption is an equilibrium process; that is, it depends on the concentration of the potentially adsorbable material in the water surrounding the grains of sediment. If the sediment with its adsorbed load is removed and placed in water of different chemical character than the water in which the adsorption took place, the adsorbed chemical may be released. The problem of equilibrium should be borne in mind when contaminated sediments are transported or stored.

Some of the dense hazardous chemicals are themselves (or can produce) strongly acidic or basic solutions (e.g. aluminum chloride or calcium oxide). Many types of sediments contain appreciable quantities of calcium carbonate (e.g. limestone) and are capable of reacting rapidly with acidic solutions to produce carbon dioxide and soluble calcium salts. The ability of most sediments to neutralize bases is much more limited because these reactions are very slow. In addition to neutralization, other types of replacement reactions can occur. For example, the relatively soluble compound, barium carbonate, will react with the sulfates often present in natural aquatic systems to form dense, insoluble, and nearly harmless barium sulfate. In general, chemical reactions that naturally occur in sediments reduce the adverse effect of chemical spills.

Biologically moderated reactions in sediments also affect the fate of spilled dense chemicals. Most reactions involving organisms take place over long periods of time, but can produce important changes in the toxicity and/or availability of spilled materials. Metallic mercury, for example, would be relatively inert and immobile in sterile sediments, but bacterial activity can produce volatile organo-mercury compounds (methyl-mercury) that are many times more toxic and more mobile than the metal itself.

Many of the chlorinated hydrocarbons are fat-soluble--not water-soluble--and hence are not directly available in high concentrations in an aqueous environment. However, once assimilated by an organism they concentrate and are held in fatty (lipid-rich) tissues; thus, they are carried by the organisms and accumulate (often to dangerous levels) throughout the food chain. Some biologically moderated reactions taking place in sediments can break down or detoxify harmful materials, but these reactions are usually so slow that they are not a useful short-term solution to controlling contaminants.

2.3 RATIONALE FOR RESPONSE RECOMMENDATIONS

By considering both the nature of the chemical spilled and its interaction with sediments, it is possible to develop a recommended response procedure. The response options that are available include:

- <u>a.</u> Removing the spilled material and surrounding sediments using dredging and/or pumping techniques (Chapter 4).
- <u>b</u>. Burying the material in place using a suitable covering material (Chapter 5).
- c. Reacting the spilled material with a reagent that will render it safe or at least lessen the hazard (Chapters 5 and 6).
- $\underline{\mathbf{d}}$. Reacting and removing the spilled material as the reacted product (Chapter 6).
- e. Reacting and burying the spilled material as the reacted product (Chapters 5 and 6).
- f. Allowing the material to remain on the bottom of the waterway, taking no action.

Any decision as to response technique will be based on:

- o Immediate and ultimate danger to local population and local biological communities from the spill,
- o Difficulty and danger encountered with removal or burial, and

o Possibilities of producing a safe or safer product by reacting the spilled material with a suitable reagent.

In the majority of spill incidences involving these 70 materials, the high degree of danger associated with the material will require its recovery. Most of the materials considered are toxic liquids that would likely be dispersed by attempts at burial and whose burial may not effectively isolate the material from susceptible organisms in its vicinity. In most waterways, burial is an uncertain procedure that may be reversed by scour and erosion resulting from bottom currents and turbulence, despite counteractive efforts.

Burial is an acceptable first choice and final solution only in cases where the material is so innocuous that its reexcavation by tides or currents would not significantly endanger the surroundings. In most cases where burial would be acceptable it would be done for aesthetic purposes rather than to prevent serious poisoning from occurring. Solid materials such as asphalt or sulfur are the best candidates for burial, but these are such comparatively harmless materials that leaving them uncovered would be nearly as safe an option. Burial would prevent fouling of beaches or shorelines from the spill.

A few materials on the list of hazardous chemicals can be reacted to produce innocuous products that can remain on the bottom of a waterway with a minimum hazard to local organisms. Barium carbonate can be reacted with a suitable sulfate (sodium sulfate and/or calcium sulfate). The resulting barium sulfate is very insoluble and if calcium sulfate is present will not be remobilized by sulfate-reducing bacteria.

In some cases it may be reasonable to react the spilled material with a reagent to decrease the spread of contaminants during retrieval. Aluminum fluoride, for example, is relatively soluble. Treating a spill of this material with calcium hydroxide would reduce the immediate danger to surrounding areas from high levels of dissolved fluoride. The fluoride would be held as the far less soluble calcium fluoride. Calcium fluoride would be less of a hazard during recovery than aluminum fluoride.

Burial of a reacted material presents the same problems as does burial of spills in general, in that the material must be so innocuous that any natural reexcavation would not endanger the surrounding organisms. Most reacted material that could be safely buried could also be left uncovered on the bottom. For example, barium carbonate reacted to barium sulfate would be a safe material for burial, but would be equally safe on the surface of the sediment. However, it may be desirable to use an inert burial material to temporarily isolate the active reagent and spilled material long enough to allow the desired reaction to be completed.

The last option, that of allowing the spill to remain uncovered and unreacted on the bottom, is only reasonable when the material is non-hazardous in its original state and does not endanger the aesthetic aspects of the environment. Only the most inert material such as asphalt or sulfur lost in deep, undisturbed water would present an acceptable situation for employing this response.

This review of response options suggests that in the majority of cases it will be necessary to depend on removal or recovery of material as the major technique for ameliorating the effects of a spill. In some circumstances combinations of these responses may be appropriate. For example, the major part of a spill may be recovered and minor amounts on the fringes of the spill area and/or any residual material left may be isolated by burial. There will doubtless be instances where recovery simply is not possible; in such cases burial, chemical reaction, containment, or even dispersion may be the only options possible. Obviously, such determinations must be made on a case-by-case basis.

The recommended responses given for each chemical in Tables 2-1 and 2-2 generally reflect the ideas expressed above. Additional discussions of chemical considerations are found where appropriate in the following chapters on dredging, burial, and other response techniques.

3.0 SPILL SCENARIOS

3.1 INTRODUCTION

The purpose of this chapter is to present, with appropriate rationale, a set of spill scenarios specifically suited for use with hazardous chemicals that sink. The spill scenarios are intended to be used not only to classify spills in the initial phases of a response effort, but also as a framework for the evaluation of various dredging, burial, and other response techniques.

This chapter addresses the incidence of spill occurrences and outlines the most typical sets of circumstances under which spills might occur. In order to accomplish the spill scenario development, a literature survey covering major spill incidents was accomplished, and several interview sessions with Coast Guard personnel were held. The result of these efforts is a matrix that combines spill sizes with aquatic settings. This matrix provides a basis for assessing the feasibility of response techniques for sinking chemical spills.

3.2 DEVELOPMENT OF SCENARIOS

Table 3-1 depicts the recommended spill scenarios against which possible response techniques will be evaluated in Chapters 4, 5, and 6 (Tasks II, III, and IV, see section 1.5, page 4). Twelve spill scenarios are generated by considering three spill volume size ranges, each with any of four general environmental settings or circumstances. A list of those site-specific environmental or physical factors which would be critical in influencing response decisions (i.e., whether cleanup is possible and which techniques are appropriate) is given for each setting.

3.2.1 Spill Size Categories

The degree of hazard associated with the specific chemical, the environmental setting surrounding the spill, and the areal extent of the contaminated zone will probably contribute more to the response decisions in many actual spills than will the volume or weight of hazardous chemicals discharged. There is certainly a loose correlation between the actual amount of material discharged and the area of the contaminated

Table 3-1 SPILL SCENARIOS

zone; however, for most dredging and burial techniques, the parameters of importance are volume of bottom material to be dredged and treated or, in the case of burial, the size of the area to be covered. Nevertheless, a useful set of spill scenarios must convey immediately a sense of the overall magnitude of the problem, and for this purpose the volume of material discharged is quite appropriate. Spill size (weight or volume) is usually known and does not depend on extensive sampling and underwater surveys. Furthermore, for some responses (e.g. chemical treatment, adsorption, or neutralization), the amount of hazardous material on the bottom must be known. Thus, to include the amount of hazardous material discharged in the array of spill scenarios is considered to be the most practical approach.

Three spill size ranges selected for use in the spill scenario matrix are given in Table 3-2. The volume categories listed in Table 3-2 were selected because they represent the capacities and multiples of common chemical transportation containers. They do not coincide with size categories used for oil spills. For the purposes of convenience, 15 lb of solid contaminant is assumed to equal 1 gal of pollutant. This is equivalent to a specific gravity of 1.81, which is very close to the median specific gravity of 1.7 for the 27 solid chemicals considered for this study.

3.2.2 Environmental Conditions

The four categories used to describe the environmental setting (Table 3-1) under which a spill occurs encompass all possible spill locations and situations and represent useful divisions in the sense that spills within each environmental category: (1) will frequently be of a similar magnitude due to typical transportation systems associated with each category; (2) will often encounter similar combinations of site-specific environmental factors; and (3) will generally produce similar classes of recovery problems requiring similar decisions, equipment, and operations. These four categories also reflect easily identifiable, real-world situations which would allow easy entrance into an indexed response manual.

Table 3-2
Spill Size Classification Used in This Study

Size	Volume	Weight	Typical
Designation	Limits	Equivalent Solids	Containers Involved
Small	Less than	Less than	Up to 18 conven-
	1,000 gal*	15,000 lb	tional 55-gal drums
Medium	1,000 to 50,000 gal	15,000 to 750,000 lb	Most highway tank trucks (<8000 gal) and most railway tank cars (8,000- 40,000 gal)
Large	Greater than 50,000 gal	Greater than 750,000 lb	Most chemical barges (<70,000 gal)

^{*} Units of measurement can be converted as shown on page iii.

- 3.2.2.1 General Spill Settings. Any chemical spill that will require the attention of the Coast Guard can be classified into one of the following four general settings, which together with the three spill size ranges discussed in a previous section, constitute the 12 basic spill scenarios (Table 3-1).
 - a. Land and nonnavigable waters. Includes spills occurring on dry land, beaches, highway or railroad drainage ditches, and nonnavigable streams.
 - <u>b. Rivers.</u> Includes navigable rivers, canals, and other freight-carrying waterways of a linear character such as intracoastal waterways.
 - c. Ports and harbors. Includes most tidal or nontidal harbors and encompasses generally quiescent waters with heavy shipping traffic and many man-made structures.
 - d. Open waters. Includes bays, sounds, estuaries, large lakes, coastal ocean waters, high seas, and other expanses of water generally away from intense traffic and port facilities.

An additional advantage in using these four basic settings is that they are compatible with the Coast Guard's Pollution Incident Reporting System (PIRS). Although the PIRS breakdown of environmental settings is somewhat more detailed (five inland and six coastal categories), the data are easily condensed into the four categories proposed here. Information taken from 1970-1975 PIRS data shows the breakdown of spill incidents other than oil (Table 3-3).

Setting	Number	Percent
Land and Nonnavigable Water	111	5.8
River	480	25.2
Port and Harbor	554	24.0
Open Water	769	40.0
Total	1914	100.0

3.2.2.2 Critical Factors Within Each General Setting. Although the 12 basic spill scenarios (three spill size ranges versus four general environmental settings) accommodate and roughly categorize all possible spills, they do not describe in sufficient detail the numerous physical and environmental factors that would influence selection of a course of action. It was therefore necessary to identify, within each general setting, those site-specific variables, such as current velocity, depth, bottom conditions, etc., which would be critical in assessing a spill and evaluating possible responses. Some factors important in one general setting would not be a major consideration in another setting (e.g., wave height in the land and nonnavigable water setting). The omission of a particular factor in a given case does not necessarily mean it has no effect, but rather that it is probably subordinate in importance to other considerations.

The site-specific factors selected under each general setting are given and ranked in Table 3-4, and those selected as critical are shown in the spill scenario matrix itself (Table 3-1). The basis for the importance assigned to any factor in Table 3-4 is a result of the views

Table 3-4 Site-Specific Environmental Factors Ranked as to Impact on Response to Sinker Spill in Indicated Setting

	Land and Nonnavigable Waters*	Rivers	Ports & Harbors	Open Waters
Biota endangered	1	1	1	1
Bottom configuration (pockets, coves, natural depressions, etc.)	3	1	2	3
Bottom type (sand, siit, rock, etc.)	1	1	1	1
Current velocity Surface Bottom	2 2	1 1	2 2	2 2
Debris	3	1	1	2
Depth	3	1	1	1
Downstream or local use	1	1	1	1
Flow (volume/time)	1	1	2	2
Man-made obstacles or structures	2	1	1	3
Salinity	3	2	1	1
Temperature Air Bottom	3 3	3 3	3	3 3
Tide	3	2	1	1
Traffic	3	1	1	2
Turbidity	3	1	1	2
Wave height	3	2	2	1
Weather conditions (fog, ice, etc.)	2	1	1	2
Width of channel	3	1	2	3

^{* 1 =} Critical

^{2 =} Important, but less than critical
3 = Probably of subordinate importance or not occurring in particular setting.

expressed by Coast Guard Captain of the Port (COTP) and Strike Team personnel interviewed during the first phase of this study coupled with the judgment of the authors.

It is essential to note that no attempt has been made to preassign specific values, ranges of values, or descriptions to the critical site-specific variables within each general setting. The virtually limitless combinations of possible conditions at an actual spill site would make such an effort fruitless, and even if it were possible, such a system would lack the flexibility needed. To simply designate the site-specific factors that are considered to be critical in formulating a course of action and to evaluate various possible responses against only the general environmental settings is considered by the authors to be the most useful approach from a practical standpoint—one that will provide needed guidance to a decision maker, but allow him the flexibility required for individual judgments based on the situation.

4.0 DREDGING TECHNIQUES

4.1 INTRODUCTION

In Task II, the potential use of dredges to recover hazardous chemicals or contaminated sediments from the bottoms of waterways was investigated. The principal effort was directed toward characterizing all pertinent aspects of the American dredging fleet (number, types, location, availability, capabilities, limitations, and costs), with secondary emphasis on the (generally) superior European and Japanese dredging industries. In conjunction with characterizing the various dredges, a parallel effort was directed at identifying the special problems that would be involved with attempting to dredge hazardous materials and assessing the probable suitability of each type of dredge in this role for each of the four general spill settings established in Chapter 3.

Sections 4.2 through 4.5 are devoted to various aspects of dredges and dredging in general and dredging of hazardous materials in particular. Section 4.6 contains the evaluation matrices in which each major type of dredge is numerically rated as to its potential utility in each general spill setting. Between the information presented in the initial sections and the qualitative evaluations in the matrices, a useful summary of dredging technology is provided, particularly as applied to hazardous material recovery. Additionally, those dredging systems with the greatest potential for use as well as information gaps and potential research areas are identified.

For purposes of this report, any equipment or device that could be used to remove material from the bottom of a waterway or from a surface spill is considered dredging equipment. This includes handheld suction equipment and land-based construction equipment (e.g., power shovels, draglines, backhoes, front loaders, dozers, etc.).

4.2 DREDGING PRACTICE AND EQUIPMENT

4.2.1 Dredging Overview and Applicability to Hazardous Material Recovery

Dredging equipment and methods have been developed over the years to enhance one of the two basic uses of dredging, namely:

- o Underwater excavation to provide or maintain navigable water depths in harbors and channels.
- o Underwater mining and sand and gravel production.

The dredging process itself involves four basic tasks: (1) the loosening or dislodging of sediment by mechanically penetrating, grabbing, raking, cutting, drilling, blasting, or hydraulically scouring; (2) a lifting action accomplished by mechanical devices such as buckets or by hydraulic suction; (3) the transporting of dredged material by pipelines, scows, hopper dredges, or trucks; and (4) disposing of the material by discharging from a pipeline either into a confined disposal area or back into the waterway by dumping from trucks, bottom dumping, or pumping out of scows or hoppers. In some hydraulic operations all four actions are carried out continuously and concurrently by a single piece of equipment, but in others the various functions are performed separately and intermittently, utilizing two or more pieces of equipment. For instance, where dredging equipment does not have onboard storage capability or where environmental considerations preclude the possibility of disposing of the material into open water adjacent to the dredging site, auxiliary equipment such as scows or barges is required for storage and transport of the dredged material.

Dredging practices in the United States have evolved to achieve the greatest possible economic returns through maximizing production with only secondary consideration given to environmental or aesthetic impacts. The type of equipment and methods used in a given job have been traditionally based on the following very practical considerations:

- o Type and amount of sediment to be dredged.
- o Physical and hydrologic characteristics of the dredging site.
- o Water depths in the area to be dredged.

- o Dredged material disposal considerations.
- o Availability of dredging equipment.

Conventional dredges are not specifically designed or intended for use in recovering spilled hazardous materials resting on the bottom, but are the logical and perhaps only feasible means to this end. The considerations listed above are no less important in planning a chemical spill response than in planning a normal dredging operation; however, additional factors must be considered because hazardous materials are involved, among them:

- o Need for precise determination and marking of boundaries of area to be dredged.
- o Need for very precise lateral and vertical control of dredging head.
- o Requirement for special precautions tailored to specific chemicals (see Tables 2-1 and 2-2).
- o Requirement for temporary storage, transport, and treatment prior to disposal of dredged material.
- o Need to predict the likely damage to aquatic and benthic organisms to be caused by the dredging operation and its effect on resuspension of any contaminant.

With several exceptions brought out in Chapter 2, the particular chemical involved in the spill will not be an important factor in choosing the best dredging equipment for the job, although onsite precautions and treatment/disposal arrangements must fit the specific nature of the chemical. In many instances, the contaminating material will be incorporated into the local sediments and will not have an identity of its own; it will be recovered along with the sediment-water slurry as "contaminated dredged material." In those cases where the chemical is still present on the bottom as an intact mass, then its properties (principally whether it is a solid or liquid) may influence dredge selection.

Dredging alone can seldom be expected to accomplish total recovery of spilled chemicals. Accordingly, it should be considered in combination with other measures, such as burial or in-place chemical treatment. These methods would be particularly applicable around the ill-defined

periphery of a spill where contaminant concentrations may be too low to justify continued dredging due to the amount of material that would be involved. Dredging should also be considered as a possible follow-up measure after the contaminant is buried with an inert or active material or immobilized by covering with a man-made sorbent material such as activated carbon. A two-stage response such as that described would have the advantages of quickly mitigating the acute hazards by burial, but nevertheless ultimately removing the chemical from the environment. Moreover, dredging of a chemically or physically tied-up material would result in less hazard from resuspension.

In addition to recovery of the contaminant, dredging could play additional roles in an overall response effort. In attempts to contain the dispersion of a chemical moving on the bottom under the influence of gravity or currents, dredges could be used to excavate trenches or build up underwater dikes, both to act as barriers. The same functions could also be useful in controlling or containing the spread of a cover material. These applications are discussed in greater detail in Chapters 5 and 6.

Previous experience with the use of dredges to clean up hazardous chemical spills is extremely limited. The only major incident from which significant lessons have been learned was the accidental discharge and nearly complete cleanup of 265 gal of polychlorinated biphenyls (PCB's) in a barge slip in the Duwamish Waterway in Seattle harbor. The cleanup effort is well documented in the after action report and summary 10 prepared by the Seattle District, Corps of Engineers -- the agency tasked with cleaning up the spill--and in a case history 11 of the incident written by James C. Willmann of the EPA's Region X. This case history is reproduced here in Appendix A. The lessons learned in this episode, both technical and practical, have been heavily drawn upon for many of the assessments and judgments found in this report. In related applications, 12 the Japanese have extensively dredged harbor sediments that were dangerously contaminated with heavy metals and organic chemicals. In these cases, there were no spills as such and thus there was no sense of responding to an accident. The primary value to be derived from the Japanese experiences is in the precise, tightly controlled dredging operations

and in the effective in-line dredged material treatment, chemical fixation, and disposal scheme. The proprietary name for one of these systems is TST (Takenaka Sludge Treatment). ¹³ Another Japanese firm has designed, fabricated, and demonstrated a special dredging head for cleaning up contaminated sediments; the device minimizes resuspension and turbidity and follows the contours of the bottom, taking a constant-thickness cut. ¹⁴ On a much smaller scale, the EPA has conducted tests using the MUDCAT dredge to recover spills of simulated solid hazardous materials. ¹⁵ The EPA has also sponsored the dredging of a reach of the Little Menomonee River (Wisconsin) bed that had been contaminated with creosote wastes. ¹⁶ This demonstration study featured a trailer-mounted physical chemical treatment train to process the contaminated sediments.

As a general statement, it appears at this point that existing dredging technology could be effectively used to recover spilled hazardous chemicals with adverse environmental impacts greatly exceeded by the beneficial environmental impact of removing the offending material. However, lack of experience in this role and the need for careful planning of not only dredging, but treatment and disposal operations as well, will mean very long lead times. Even the Japanese, who have the most experience in this area, do not undertake such operations as a "response."

4.2.2 Description of Dredging Equipment and Operations

Dredging equipment and its nomenclature resist neat categorization. As a result of specialization and tradition in the industry, numerous descriptive, often overlapping, terms categorizing dredges have developed. For example, dredges can be classified according to: the basic means of moving material (mechanical or hydraulic); the method of storage or disposition of dredged material (pipeline, sidecaster, hopper); the device used for excavating sediments (cutterhead, dustpan, plain suction); the type of pumping device used (centrifugal, pneumatic, airlift); and others. Dredges do not come in standard models, but in fact are more likely to be designed for a specific type of job and repeatedly modified

to suit the requirements of new owners or new tasks. Dredges range in size from the MUDCAT, only 30 ft long, to 350-ton, barge-mounted cutter-heads and 350-ft, oceangoing hopper dredges.

For purposes of this report dredges will be classified as mechanical, hydraulic, pneumatic, and special purpose. It is recognized that these categories are neither mutually exclusive nor parallel; however, with proper explanation they will prove to be convenient and cause a minimum of confusion.

Mechanical dredges remove bottom sediment through the direct application of mechanical force to dislodge and excavate the material at almost in situ densities. Most mechanical dredges deposit the dredged material into scows or barges for transportation to a disposal site. Specific types of mechanical dredges in common use are the dipper, the bucket ladder, and the grab or clamshell.

Hydraulic dredges remove and transport sediment in liquid slurry form. They are usually barge-mounted and carry diesel or electric-powered centrifugal pumps with discharge pipes ranging from 6 to 48 in. in diameter. The slurries containing 10 to 20 percent solids by weight are often transported several thousand yards through pontoon-supported pipelines to a water or land-based disposal site. Other methods of handling dredged material include sidecasting (to be explained below), loading into barges or scows, and direct loading of onboard hoppers. Dredge types to be discussed under this category include plain suction, dustpan, cutterhead, and hopper dredges.

Pneumatic dredges are treated as a distinct category only because of their comparative novelty in this country. Originally developed in Italy under the trade name Pneuma, these systems feature a pump that operates on compressed air and hydrostatic pressure and that is reported to be capable of handling slurries up to 70 percent of the in situ sediment density. Reliable data on the percent solids by weight are unavailable at this time. Pneumatic dredges are otherwise hydraulic pipeline systems.

The special purpose category of dredges includes the MUDCAT, a readily available, scaled-down hydraulic dredge, any of the various hand-

held suction devices or portable pumping systems that could be used for hazardous material recovery, and the whole range of land-based construction equipment that would be invaluable in the case of a land spill (front loaders, backhoes, power shovels, scrapers, draglines, etc.).

With the exception of seagoing hopper dredges, most conventional barge-mounted dredges are not self-propelled, but are moved and controlled by systems of cables and winches, often anchored to points on shore. Some hopper barges are guided by tugs or onboard engines.

Figures 4-1 through 4-9* are simplified line drawings of each major type of dredge. They should be referred to during subsequent discussions of each dredge.

4.2.2.1 Mechanical Dredges. Dipper dredges (Figure 4-1) are capable of exerting great mechanical effort and are frequently used in the subaqueous excavation of soft or broken rock and dense sedimentary deposits such as clay and glacial till. A bucket is firmly attached to a long boom and is forcibly thrust into the material to be removed. To increase digging power, the dredge barge is moored on powered spuds that transfer the weight of the forward section of the dredging vessel to the water bed. The violent action of this type of equipment may cause considerable sediment disturbance during digging and a significant loss of fine material from the bucket during the hoisting process. Dipper dredges normally have a bucket capacity of 8 to 12 cu yd and a working depth of up to 50 ft. There is great variability in production rates but 30 to 60 cycles per hour is routinely achieved. Dipper dredges are inherently better adapted for working in horizontal rather than vertical planes.

The <u>bucket ladder dredge</u> (Figure 4-2) is composed of an inclinable ladder supporting a continuous chain of buckets that move around two tumbler pivots. As the buckets revolve around the lower tumbler, material is scooped up and transported up the ladder, and as the buckets

^{*} Adapted from "Evaluation of Procedures for Removing and Decontaminating Bottom Sediments in the Lower Great Lakes," Canada Department of the Environment. 18

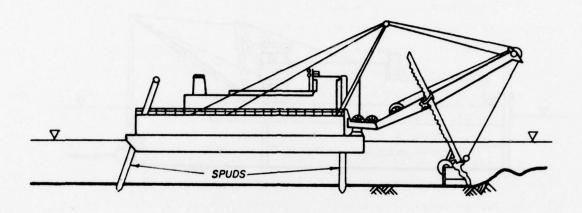


FIGURE 4-1. DIPPER DREDGE.

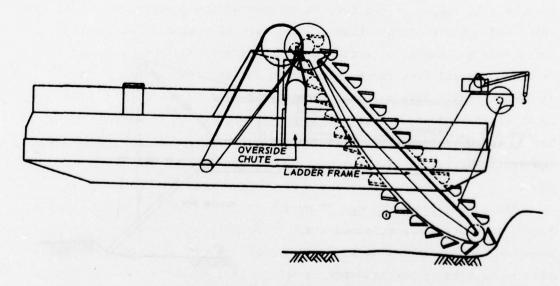


FIGURE 4-2. BUCKET LADDER.

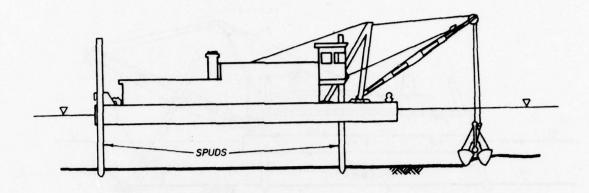


FIGURE 4-3. CLAMSHELL DREDGE.

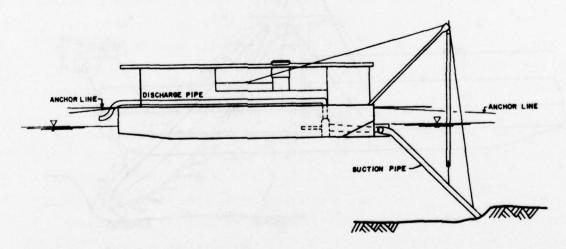


FIGURE 4-4. PLAIN SUCTION DREDGE.

pass around the upper tumbler the material is dumped into a trough. As with the dipper dredge, considerable sediment disturbance and loss of fines back to the water column are virtually unavoidable. There are only four bucket ladder dredges known to be operating in the United States (used for mining operations), and therefore the use of this equipment to retrieve hazardous materials from waterways by the Coast Guard is highly improbable.

Grab and clamshell dredges (Figure 4-3) are crane-operated devices. They may be used to excavate most types of materials except for the most cohesive consolidated sediments and solid rock. Grab and clamshell dredges are frequently used in confined areas where close control of position and depth is essential to avoid undermining the foundations of marine structures. These dredges usually excavate a heaped bucket of material, but during hoisting drag forces wash away part of the load. Once the bucket clears the water surface, additional losses may occur through rapid drainage of entrapped water and slumping of the material heaped above the rim. Loss of material is also influenced by the fit and condition of the bucket, the hoisting speed, and the properties of the sediment. Even under ideal conditions, substantial losses of loose and fine sediment will usually occur. Clamshell dredge buckets range in capacity from 1 to 12 cu yd. The crane is normally mounted on a flatbottomed barge, but may also be found on other vessels, on fixed-shore installations, or on a crawler mount. Twenty to thirty cycles per hour is typical, but large variations exist in production rates because of the variability in depths and working media. The working depth of the clamshell is theoretically limited only by the cable length. Most actual dredges can work at depths up to 100 ft or more. To reduce the probability of fines and loose material escaping from the bucket during the hoisting operation, the Japanese 19 have designed and fabricated a bucket that is completely closed and sealed by flexible gaskets. This modification has not been used in the United States because the need for controlling turbidity has not had a high priority, but could readily be made with relatively small outlays of capital.

4.2.2.2 Hydraulic Dredges. The plain suction dredge, as the name implies, relies solely on the suction generated by the centrifugal pump to dislodge, capture, and transport the excavated slurry. It is the simplest of the hydraulic dredges. The passive dredging head is located at the lower end of the ladder -- the hinged frame structure that supports and controls the suction pipe (see Figure 4-4). The ladder is lowered and raised by cables attached to the A-frame. Plain suction dredges are most effective in pumping free flowing materials such as sand and unconsolidated sediments. Because no digging or agitating devices are available to loosen the sediments, this type of dredge is not useful against hard or cohesive bottom materials such as consolidated clay sediments. During normal operations material with solids contents of 10 to 15 percent by weight are drawn from the bottom up through the suction line and discharged into a scow or through a pipeline to a nearby disposal site. Plain suction dredges are commonly used for sand mining, beach restoration, general river channel maintenance, and scow unloading. The production rate of suction dredges depends on the pipe size and pump horsepower as well as the type of material being dredged. Table 4-1 shows pipeline discharge rates in cubic yards per hour for various common pipe diameters as a function of discharge velocity.

A specialized class of plain suction dredge that is usually found on oceangoing hopper vessels is the sidecaster, whose name describes a technique for dredged material disposal. The dredged material is removed from the sediment bed and instead of being deposited in a hopper or in a disposal site is purposely redeposited alongside the dredged channel back into the waterway. Sidecasting dredges would generally be unsuitable for hazardous material retrieval, for obvious reasons.

The <u>dustpan dredge</u> (Figure 4-5) is a hydraulic suction dredge that utilizes a widely flared dredging head along which are mounted high-pressure water jets. The powerful jets loosen and agitate the sediments which are then captured in the dustpan head as the dredge itself is winched forward into the excavation. Dredged material slurries with solids contents of 10 to 20 percent by weight are common with dustpan dredges. While the high pressure jetting action may improve efficiency

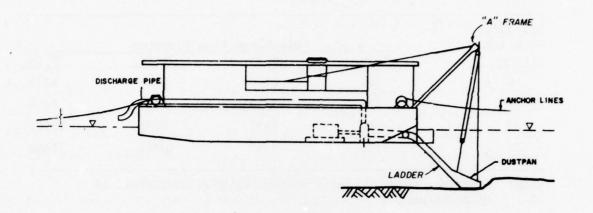


FIGURE 4-5. DUSTPAN DREDGE.

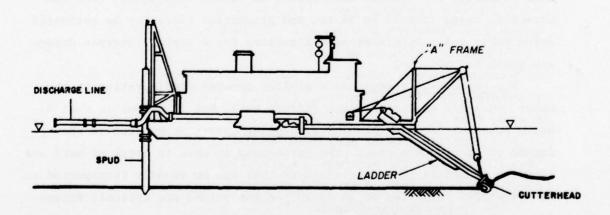


FIGURE 4-6. CUTTERHEAD SUCTION DREDGE.

Table 4-1²⁰
Suction Dredge Pipeline Discharge Rates
Cubic Yards per Hour

Discharge Velocity		Discharge Pi	pe Diameter	
ft/sec	8 in.	18 in.	24 in.	30 in.
10	481	2228	4016	6274
15	719	3339	6024	9414
20	960	4453	8033	12551
25	1200	5567	10041	15688

Note: Discharge velocity under routine working conditions is 15-20 ft/sec.

slightly (in terms of slurry density) and will allow cohesive sediments to be dredged, it may also produce considerable resuspension of fine-grained materials into the water column. All dustpan dredges in the United States are owned by the U. S. Army Corps of Engineers and are used primarily for channel maintenance in inland waterways. Pipeline diameters range from 24 to 34 in. and production rates may be estimated using Table 4-1. Pertinent specifications for a typical dustpan dredge are given in Table 4-2.

The <u>cutterhead dredge</u> has a similar general configuration to the other hydraulic suction dredges (Figure 4-6), but is unique in that it has a powerful rotating mechanical digging apparatus mounted at the intake of the suction pipe. The cutterhead is used to break up hard and cohesive materials to create a slurry that can be readily transported in the pipeline. Slurries of 10 to 20 percent solids are typical, depending on the material being dredged. Production rates as a function of discharge velocity may be estimated using Table 4-1. Specifications and dimensions of several cutterhead dredges ranging in pipe diameter from 6 to 30 in. are given in Table 4-2. Cutterhead dredges become in effect plain suction dredges when and if the cutterhead is turned off or removed. Cutterhead dredges also differ from other hydraulic suction dredges in the unique movement pattern with which they progress through

Table 4-2 Specifications for Typical Dredges of Various Types

Pipeline Diameter in.	Weight Length	Midth ft	Height ft	Draft In.	Freeboard in.	9	Dredge	Dredge Pumps Hp Size	Drive	Production Rate cu yd/hr	Dredging Depth ft	Maximum Depth of Single Pass Excavation in.	Remarks
- 244		20	09	09	87	-	2100	38	Steam	3500	09	09	
		п:	20	34	14	-	175	00	Diesel	25-95	12	18	Portable
72.5 90		11	33	43	11		335	17	Diesel	60-300	12	18	Portable
		20	33	42	18	-	520	14	Diesel	120-540	22	18	
		50	33	43	17	-	520	16	Diesel	160-700	25	21	
		32	20	54	17		1125	18	Diesel	310-1365	0,0	27	
		32	20	26	07	-	2250	24	Diesel	515-1615	20	30.	
		36	67	09	36	-	3600	90	Diesel	575-2500	20	36	
50 115*		32*	82*	63	33	8	710	×	Diesel	960-390	65 *	39	Portable
13.9 30		∞	5	18	12	-	175	∞	Diesel	60-150	15	18	Portable

* Floating plant - see Appendix C for individual equipment dimensions.

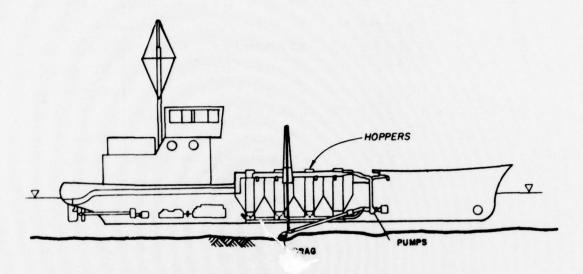


FIGURE 4-7. HOPPER DREDGE.

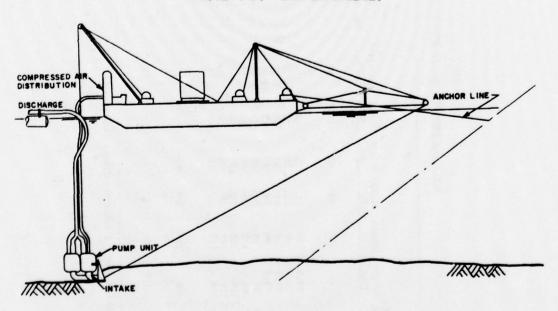


FIGURE 4-8. "PNEUMA" DREDGE.

the work area. Whereas other dredges normally are winched, or otherwise pushed or pulled in a straight line, the cutterhead dredge alternately anchors itself on one of two stem-mounted spuds (hydraulically activated pylons) and using the spud as a pivot, draws itself along moored swing wires in a short horizontal arc about the spud. Applying this technique repeatedly while alternating spuds, a dredge will cut a wide, herringbone-like swath through the work area. Cutterhead dredges are the workhorses of the United States dredging fleet.

Hopper dredges (Figure 4-7) are equipped with large centrifugal pumps similar to those employed by the other suction dredges but are mounted on self-propelled, seagoing vessels instead of barges. The suction pipes are hinged on each side of the ship with the intake or drag arm extending downward toward the stern of the vessel. The head is dragged along the bed of the area to be dredged as the vessel moves forward at speeds up to 13 km/hr. 25 Dredging is accomplished by making progressive traverses over the excavation area. The dredged material is lifted up the suction pipe and deposited and stored in the hold or hopper of the ship. During normal dredging operations, the heavier sediments tend to settle out in the hopper while excess water usually containing considerable fine-grained material in suspension is allowed to flow over weirs in the hoppers back into the water body. Using this equipment for the retrieval of hazardous materials from the bed would require that unrestricted overflow of the hoppers be eliminated. Once fully loaded, hopper dredges must move to a disposal site to unload before resuming dredging. Normally, unloading is accomplished by opening doors in the bottom of the hoppers and allowing the contents to drop out and sink to the ocean bottom--a practice that would be patently unsuitable for most contaminated dredged material. In these cases pumping out of the hoppers to a land or floating treatment plant or safe disposal site will normally be necessary. Some hopper dredges are equipped with built-in pump-out capability (see Table 4-3) while others would have to use auxiliary equipment. While specifically designed drag heads are available for use in raking and breaking up hard materials, hopper dredge dragheads are normally most efficient in excavating loose,

Table 4-3 Pertinent Characteristics of Corps of Engineers Hopper Dredges

	Hopper	Dredg	Dredge Pumps	Speed, mph	Hull			Dredging	Vertical	Owning
Name	capacity cu yd	Number	Size	Light	Matl	Beam	Draft	Depth	Clearance	District Remarks*
BIDDLE	3060	1150	28" Electric	17.3	Steel 351'9"	30.0"	24,6,,	62.0"	83.0.,	Portland
COMBER	3710	1150	28" Electric	15.3	Steel 351'9"	30.0"	24.4"	62.0"	.0.56	Philadelphia (a)
DAVISON	720	410	20" Electric	13.6	Steel 215'10"	40'4"	12'7"	45.0"	80.0,	Jacksonville
ESSAYONS	8277	2 1850	32" Electric	17.3	Steel 525'2"	72'0"	30, 7"	0.09	104.0	Philadelphia
GERIG	3060	2 1150	28" Electric	15.8	Steel 351'9"	30.0"	24,4"	62.0"	92'4"	Galveston
COETHALS	6422	1300	30" Electric	14.5	Steel 476'5"	36'3"	29'6"	0.09	104.0.	Philadelphia (a)
HAINS	882	410	20" Electric	14.1	Steel 215'10"	15'6"	13'0"	36'0"	0.69	Detroit (b)
HARDING	2680	1000	20" Diesel	14.6 12.6	Steel 308'2"	56'0"	22'6"	0.59	92.0"	Portland
HOFFMAN	920	410	20" Electric	14.1	Steel 215'10"	15'6"	12'9"	36.0"	0.89	Buffalo (a)
нуре	720	410	20" Electric	13.8 12.6	Steel 215'10"	40'4"	12'7"	42.0	71'6"	Jacksonville
LANGFITT	3060	1150	28" Electric	15.4	Steel 351'9"	30.0"	24'4"	62'0"	0.06	New Orleans
LYMAN	920	410	20" Electric	13.6 12.6	Steel 215'10"	15'6"	13'0"	42.0.,	0.01	Buffalo (a)
MACFARLAND	3140	1867	34" Electric	15.4	Steel 319'8"	72'0"	22'0"	25.0"	.06	Jacksonville (b)
MARKHAM	2680	650	23" Electric	16.7	Steel 339'6"	62'0"	19.4"	45.0	.06	Buffalo (a)
PACIFIC	200	340	18" Electric	11.5	Steel 180'3"	38.0"	12.0"	.0.55	0.02	Portland

* (a) = Direct pump-out capability.
(b) = Direct pump-out and sidecasting capability.

uncohesive materials. Of all the dredges discussed thus far, the hopper dredge is the only one capable of operating in rough, open waters; in relatively high currents; in and around marine shipping traffic; and in adverse weather conditions.

All 15 oceangoing, trailing suction hopper dredges currently operating in the United States are owned by the Corps although several privately owned vessels are under construction. Their hopper capacities range from 500 to over 8000 cu yd with corresponding loaded drafts ranging from 11 to 28 ft. Table 4-3 gives detailed specifications of all vessels in the Corps hopper dredge fleet. Hopper dredges are obviously meant to dredge and maintain deep shipping channels; their own drafts will usually preclude their use in river and barge channel situations.

A number of privately owned hopper barge dredges, similar in concept but not hull configuration to those described, are also in operation on the East Coast.

4.2.2.3 Pneumatic Dredges. The "Pneuma" dredging system (Figure 4-8), as developed in Italy, consists of a pneumatic pump that is normally suspended on cables from a barge-mounted crane. The 2250-cfm, $500-hp^{23}$ compressor that is required to operate the pump is located on board the barge. The pump consists of three cylinders (3.3 to 5.9 ft in diam depending on model) that are alternately filled with sediment by hydrostatic pressure; when filled they are serially emptied by closing the inlet and applying compressed air to force the contents into a common header line. The major advantage of this technique over a centrifugal pump is that the sediment does not have to be in liquid slurry form but rather, the manufacturers claim, can be handled with solids contents corresponding to a plastic state. Besides the pneumatic pump, this dredge is essentially a hydraulic pipeline system with moderate production capacity (60 to 390 cu yd/hr). 26 There is no theoretical depth limitation to the pneumatic pump, as with centrifugal pumps, and because it is crane-mounted this system would be useful in and around port structures. The normal mode of operation is with a scoop-like dredging head that is pulled with cables into the excavation, resulting

in minimal solids resuspension. Other active and passive dredging head attachments could be used with the Pneuma. An improved pneumatic pump, ¹³ available under the Japanese trade name "Oozer," uses negative (vacuum) pressure in the filling chambers instead of atmospheric pressure when dredging in shallow waters. This improves the dredge's efficiency and purportedly results in higher solids contents and higher production rates. A pneumatic dredge was used in the Duwamish Waterway PCB cleanup ¹⁰ as well as in several of the harbor clean-up operations in Japan. ¹²

The Pneuma system, including pump, air and slurry lines, compressor, crane, and barge, is not small (see Appendix B for detailed dimension and weight specifications for several Pneuma configurations), but it has the advantage of being able to be broken down into manageable components that are truck or air transportable. This feature lends an added dimension to the Pneuma for potential use in a spill response role.

Pneumatic pump systems need to be objectively tested and evaluated in comparison with conventional hydraulic dredge systems to verify their claimed superiority in the clean-up role.

4.2.2.4 Special Purpose Dredges. The National Car Rental Agency has designed and developed the MUDCAT, a small hydraulic dredge for excavating sediments up to 18 in. thick per pass from depths up to 15 ft (see Figure 4-9). The machine is pontoon-mounted and features an auger-like cutting device that feeds the sediment to the suction intake of a diesel-driven centrifugal pump. The auger is mounted along the base of a bulldozer-type blade. The whole arrangement with suction pipe attached is controlled by a hydraulic boom. The dredge is not self-propelled, but is moved along on an anchored cable during each traverse of the excavation, and the dredged material is discharged ashore through a float-supported pipeline. The width of the cut is approximately 8 ft, and applications to date have included cleaning out small reservoirs and streams. Since the MUDCAT is basically an 8-in. hydraulic pipeline dredge, production rates would be comparable to those given in Table 4-1. Refer to Table 4-2 for the MUDCAT's physical specifications.

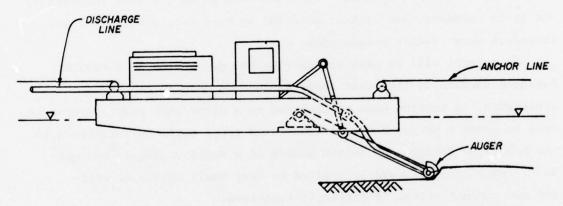


FIGURE 4-9. MUDCAT DREDGE.

An EPA study 15 concluded that the MUDCAT dredge was effective in removing undesirable particulate matter from pond bottoms. In the course of tests made during this study two significant observations were made. First, the MUDCAT was shown to have a greater efficiency in the removal of sediment during a backward cut than in a forward cut. The explanation given was that the mud shield was fully extended over the cutting auger in the backward direction and thus was more effective in decreasing the resuspension of any bottom sediments into the surrounding water column. Secondly, the specific gravity of the spilled material had a definite effect on recovery efficiency. It was observed that as the specific gravity of the target material decreased, the material recovery rate decreased and resuspension of the spilled matter into the water body markedly increased. No reason was given for this phenomenon, but it is surmised that lighter material is more easily disturbed and therefore more readily resuspended.

No attempt will be made to describe the many types of portable, handheld suction devices that could be used in many instances as a minidredge. A suction hose manipulated by a diver with pump and storage tank on board a barge, boat, or land-based truck could be invaluable in the precision dredging of intact masses of a solid or liquid contaminant. Practical use would be limited to very small spills or well-defined concentrations in difficult locations.

Land-based, earth-loading equipment ranging from farm tractor-size loaders and backhoes to giant shovels and draglines used in strip mining could have valuable application to spill response, particularly in the land and nonnavigable water scenarios. No attempt will be made to describe the various types and sizes of equipment that are available in most locations. An important source of many of these type items of equipment on short notice, depending on the location, may be engineer units of the U. S. Army, active and/or reserve.

4.2.3 Dredging Equipment Capabilities, Limitations, Advantages, and Disadvantages

Table 4-4 gives the important operating characteristics, capabilities, and limitations of each major type of dredge discussed above. In

Table 4-4 Summary of Dredge Operating Characteristics

		Percent Solids		Onorsto	Suitable		Approx.			Marimina		latorel
	loss	Slurry by	Turbidity	In Open		Vessel Draft	Production Rates	1	Dredging Depths (ft)	Wave		Dredging, Accuracy
	Liquid	Weight	Caused	Water	Retrieval	(ft)	(cn yd/hr)	Minimum	Maximum	(ft)	Current	(ft)
Dipper	high	in situ	high	yes	solid	o	30-600	p0	20	<3g	1	ж.
Clamshell or Grab	high	in situ	high	yes	solid	v	30-600	PO	150e	<38,h	+	1
Suction	low	10-15%	low	yes	both	9-6	25-10,000	9-6	50-60 ^f	<3	+	2-3
Dustpan	low	10-20%	avg.	ou	both	5-14	25-10,000		20-60 ^f	<3	1	2-3
Cutterhead	low	10-20%	avg.	yes	both	3-14	25-10,000		12-65 ^f	<3	i	2-3
Hopper	low	10-20%	avg.	yes	both	12-31	500-2,000	10-28	65 ^f	<7	1	10
MUDCAT	low	10-402	low	ou	both	14	60-150	15	15	41	+	×
PNEUMA	low	up to 80% of	low	yes	both	v	96-390	PO	150 ^e	<38,h	i	1
Handheld Vacuum	low	5-10%	low	yes	both	v	10	PO	100	<38,h	ı	ź.

....

Percent solids could theoretically be 0, but these are normal working ranges. Percent solids = wt. of dry sediment.

Limited operation in open water possible, depending on hull size and type and wave height.

Depends on floating structure; if barge-mounted, approximately 5-6 ft draft.

Zero if used alongside of waterway; otherwise, draft of vessel will determine.

Demonstrated depth; theoretically could be used much deeper.

With submerged dredge pumps, dredging depths have been increased to 100 ft or more.

Depends on supporting vessel--usually barge-mounted.

Theoretically unaffected by wave height; digging equipment not rigid.

Literature infers that water current hinders dredging operations, but references avoid establishing maximum current limitations. For most dredges, limiting current is probably in the 3-5 knot range, with hopper dredges slightly greater, perhaps 7 knots.

Vertical accuracies are generally within ±1 ft.

some cases a wide range of values is given to account for the various sizes of individual plants within each class. In other instances the information given consists of a qualitative judgment (good, average, poor) that reflects each dredge type's performance in a given area. In any case Table 4-4 should be a valuable tool in making a quick assessment of the suitability of a given dredge type in a known physical setting. Table 4-4 is presented for use in conjunction with the dredge evaluation matrices presented in section 4.6.

In the following sections a summary is given of the principal advantages and disadvantages of each dredge.

4.2.3.1 Mechanical Dredges. Mechanical dredges (clamshell, dipper, and bucket) are designed for hard or soft materials and normally are not self-propelled crafts. No provision is made for material containment; thus, these units must work along side the disposal area or be accompanied by disposal barges during the dredging operation.

Principal advantages of mechanical dredges:

- o The clamshell is capable of deep-water excavation.
- o They can be controlled and maneuvered in small and confined areas and would be useful in areas with obstructions and debris.
- o They excavate materials at nearly in situ densities; thus, a smaller volume of dredged material must be handled and disposed of.

Principal disadvantages of mechanical dredges:

- o They are capable of only modest production rate (< 500 cu yd/hr).
- o They require separate disposal vessels and equipment.
- o They cause a great deal of turbidity and sediment (contaminant) resuspension.
- o They would be ineffective against a free or unadsorbed liquid contaminant.
- 4.2.3.2 Hydraulic Dredges. Barge-mounted types, such as the plain suction, dustpan, and cutterhead dredges, will have difficulty in rough water (greater than 3-ft waves). Excessive vertical movement of the ladder can cause the head to be forced into or bounced off the bottom leading to excessive impact loads on the ladder, digging equipment, and

transmission. Additionally, large differential movement between the barge and sections of the float-supported pipeline could result in undesirable stresses and failures in rigid pipe connections.

Principal advantages of conventional barge-mounted hydraulic dredges:

- o Depending on size, they are capable of the highest production rates of any dredge (up to 15,000 cu yd/hr).
- o Pipeline directly to treatment/disposal area could minimize handling of and exposure to contaminated dredged material.

Principal disadvantages of conventional, barge-mounted hydraulic dredges:

- o They cannot be employed in rough waters.
- o The large volume of dredged material is 80 to 90 percent water, requiring major dewatering and consolidation operations for efficient disposal.
- o Anchoring cables and pipelines present temporary obstructions in navigable water channels.
- o Cutterheads and suction lines are hindered and possibly damaged by underwater debris, large rocks, and other obstacles.

The oceangoing hopper dredges are self-propelled vessels with self-contained storage of up to 8000 cu yd.

Principal advantages of hopper dredges:

- o Self-contained storage of dredged material eliminates need for separate storage barge, scow, or pipeline. Some possess pump-out capability.
- o Hopper dredges can operate in rough, open waters and relatively strong current.
- o They operate without anchors and other restraints and can be used in shipping channels without causing excessive interference with normal traffic.

Principal disadvantages of hopper dredges:

o Deep draft precludes use in shallow waters, including barge channels.

- o They cannot work continuously, but must alternately load up, move to disposal site, dump or pump out, and return.
- o For hazardous materials, the full hopper capacity cannot be used to preclude overflow.
- o Hopper dredges excavate with less precision than other dredge types.
- o Open-water dumping, though quick and efficient, cannot be used for contaminated material.
- 4.2.3.3 Pneumatic Dredges. Pneumatic dredges are basically hydraulic pipeline systems which use a compressed air-operated pumping device. Developed in Italy and Japan, they have been used successfully in a number of clean-up operations including the Duwamish PCB spill.

Principal advantages of pneumatic dredges:

- o They are crane-supported and thus can be operated in close and restricted areas and can be mounted on barges, seagoing vessels, as well as dockside.
- o They can be operated in shallow or deep water with no theoretical maximum depth.
- o They can be relatively easily dismantled and transported by truck or air (see Specifications, Appendix B).
- o They may be able to yield denser slurries than conventional hydraulic dredges.
- o With passive excavating heads they cause little turbidity or resuspension of solids.

Principal disadvantages of pneumatic dredges:

- o They are capable of only modest production rates (up to 390 cu yd/hr).
- o Cables and pipelines present temporary obstructions in navigable water channels.
- o Pneumatic systems are not in widespread use in the United States and therefore may not be as readily available as other types.
- 4.2.3.4 Special Purpose Dredges. Special purpose dredges include the MUDCAT, handheld suction devices, as well as conventional earth-loading and moving equipment. In most cases their greatest value lies

in small or surgical clean-up operations, or, in the case of earthloading equipment, land spills.

Principal advantages of the MUDCAT:

- o It is compact and readily transportable by truck or air.
- o It can be operated in confined and isolated areas and in very shallow waters.
- o It is compatible in production rate with an existing trailermounted treatment unit developed by the EPA.
- o It would be readily available for lease from the National Car Rental Corporation and might be able to be activated on shorter notice than other dredges.

Principal disadvantages of the MUDCAT:

- o Its size and production capacity would limit it to small jobs. Principal advantages of handheld suction devices:
- o They are extremely mobile and universally available.
- o With manual positioning, they are capable of surgical clean-up work.
- o They would be particularly effective in vacuuming identifiable masses of pure contaminant, particularly liquids and free-flowing solids.

Principal disadvantages of handheld suction devices:

- o They are limited to very small quantities of material.
- o They are ineffective against consolidated sediments.

4.2.4 Costs of Dredging

The cost of dredging per unit volume is extremely variable, depending on such factors as location and size of job, type of material, depth, proximity and type of disposal area, and others. Based on actual cost data compiled for Corps of Engineers dredging projects from 1972 to 1974, Table 4-5 shows the per cubic yard cost of dredging, including disposal, by type of dredge and geographical area. Figure 4-10 is a map which depicts average dredging costs (all dredge types combined) for Federal navigation projects in each of the ten Corps Divisions in the continental U. S. These figures should not be construed as the probable cost of dredging to recover spilled hazardous materials; however, they

Comparative Dredging Costs Table 4-5

				The same of the sa		
	Dipper	Clamshell	Pipeline ^b	Hopper	Pneuma	Dragline
West Coast					"	
Seattle	-	\$1.61/yd ²	\$0.76/yd	\$0.74/yd3	\$0.52/yd3	1
Portland	!	1.77/yd ³	0.45/yd3	0.31/vd3	0.31/yd3	1
San Francisco	1	1.36/yd3	1.01/yd3	0.44/vd3	0.69/vd3	1
Sacramento	!	1.43/yd ³	0.84/yd2		0.58/yd3	1
Los Angeles	1	1	0.50/yd ³	0.48/yd ³	0.34/yd ³	1
Gulf Coast			,	,	,	
Galveston	1	,	\$0.26/yd3	\$0.14/yd ³	\$0.18/yd ³	1
New Orleans	:	\$0.47/yd ³	0.24/yd3	0.12/yd3	0.17/yd3	1
Mobile	1	1	0.18/yd ³	0.29/yd ³	0.12/yd ³	1
Interior Waterways						
St. Paul	\$1.96/vd ³	•	\$0.46/vd3	\$0.99/vd ³	\$0.32/vd ³	\$2.51/vd ³
St. Louis	-	1	0.23/vd3		0.16/vd3	
Kansas City	!	-	0.65/yd3	1	0.45/yd3	1
Little Rock	1	1	0.68/yd3	1	0.47/yd3	1
Tulsa	1	1	0.69/yd3	1	0.47/yd3	1
Omaha	1	,	0.56/yd2	1	0.39/yd2	1
Huntington	1	1.56/yd3	0.67/yd3	1	0.46/yd3	1
Louisville	1	1.89/yd ³	0.28/yd ³	1	0.19/yd ³	1
Great Lakes			•	,	,	
Chicago	\$1.99/yd ³	\$1.95/yd ³	\$1.66/yd ³	\$1.97/yd3	\$1.14/yd ³	1
Buffalo	1	4.04/yd3	1	0.96/yd2		1
Detroit	!	2.01/yd ³	0.83/yd ³	1.37/yd ³	0.57/yd ³	\$2.30/yd ³
East Coast		•				
New York	1	\$1.49/yd ³	\$1.39/yd3	\$0.95/yd ³	\$0.96/yd3	1
Baltimore	1	1	1.20/yd3	0.41/yd3	0.83/yd3	1
Philadelphia	1	1	0.86/yd3	1.03/yd3	0.59/yd3	1
Norfolk	1	1	0.63/yd3	0.54/yd	0.43/yd3	•
Wilmington	1	1	0.58/yd3		0.40/yd3	1
Charleston	1	1	0.70/yd3	0.91/yd3	0.48/yd3	1
Jacksonville	1		1.24/yd3	0.79/yd3	0.85/yd3	1
Boston	1	3.38/yd ³	2.79/yd ³	2.25/yd ³	1.92/yd	1
		26/2000	2617117	2615202	261-1-1	

Data extracted from U. S. Army Engineer District Dredging Reports for 1972, 73, and 74.

Includes plain suction, cutterhead, and dustpan.

Derived from a report sponsored by the Savannah District which estimated that Pneuma dredging costs were only 70 percent of the cost experienced by hydraulic dredges. Pneuma costs may not be comparative except for jobs similar to those for which the estimate was made (barge slip cleaning).

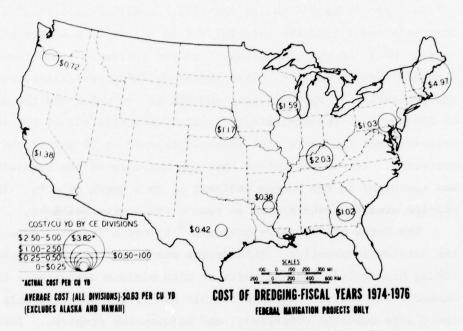


FIGURE 4-10. AVERAGE FEDERAL DREDGING COSTS.

are useful to show the variability and relative costs by dredge type and region.

The only documented case that may give a valid indication of the actual cost of hazardous material recovery is the Duwamish PCB spill in which about 240 gal were recovered out of an estimated 265 gal discharged into the waterway. At first, the material was incorrectly identified as a petroleum-based product and an attempt was made to retrieve the material from the surface of the waterway. This operation netted approximately 4 gal of material. Analyses performed on samples correctly identified the material and an operation was attempted to suction pools of the contaminant from the bottom of the waterway with handheld suction devices. This 20-day dredging operation resulted in the processing of approximately 600,000 gal of water and the collection of 215 drums of PCB-contaminated mud. Concentrations of PCB in the recovered mud indicated that approximately 70 to 90 gal of the PCB's was recovered. It was determined that the majority of the remaining PCB's was contained in the bottom sediment up to a depth of 4 ft. This precipitated the requirement to remove the bottom sediment.

The Corps of Engineers proposed 10 to use a Pneuma dredge system for the retrieval operation. This dredge was purported to be capable of removing high solids content sediment with minimum disturbance to the seabed. The overall response to this new system was favorable, but there were numerous operational and maintenance problems. These problems were rationalized with the explanation that the equipment was new and operational procedures were unfamiliar. Nonetheless, during the 30-day dredging operation that ensued, 9.5 million gal of slurry was processed and treated. It was estimated that 140 to 150 gal of PCB's was recovered. The total expenditure to recover a total of 240 gal of the PCB's was approximately \$500,000, which included treatment and disposal of the dredged material and the \$100,000 rental fee for the Pneuma system.

For the MUDCAT system, there were no data available from actual operations for establishing a cost comparison among the various geographical areas. Therefore, the following analysis is based on

equipment costs, freight charges for delivery, insurance, interest, maintenance, and operational expenses provided by the MUDCAT Division in Paramus, N.J. The depreciation schedule is based on an expected equipment life of 5 years or 10,000 hr of operation.

Equipment cost, MC-15 MUDCAT Standard accessories (which include discharge pipe and floats, cable and related harnessing equipment, service boat and motor, hand tool	\$78,750.00
set, and spare parts kit)	17,505.00
Estimated freight	2,000.00
Total Procurement Cost	\$ 98,255.00
Insurance - 5-year premium	15,000.00
Interest	57,600.00
Total 5-year Ownership Cost	\$170,855.00
Hourly ownership cost	\$17.09
Maintenance cost, hourly	8.09
Operational cost, hourly (2 operators)	20.00
Total Hourly Cost	\$45.18

Based on production rates of 60 and 150 cu yd/hr, the per yard cost is \$0.75 and \$0.30, respectively, not including disposal costs.

4.3 LOCATION AND AVAILABILITY OF DREDGES IN THE U.S.

The status of the U. S. dredging fleet as determined in the Corps of Engineers National Dredging Study is comprehensively summarized in a paper of the same title by Murden and Goodier. The U. S. Army Corps of Engineers operational fleet is comprised of 15 hopper, 3 sidecaster, 11 cutterhead, 8 dustpan, and 5 mechanical dredges. With the exception of two hopper units, all were constructed prior to 1949. In comparison with many of the modern, automated dredges now operated in Europe and Japan, the Corps' dredges are labor-intensive operations requiring 2-½ to 3 times the manpower to operate. Though the Corps' fleet is well maintained (at great expense in downtime and labor), it is nevertheless obsolescent and inefficient relative to the state of the art. Even the highly touted Corps hopper dredge fleet is badly in need of modernization.

The industrial fleet is comprised of approximately 450 plants plus approximately 250 portable MUDCAT dredges owned and available for lease from the National Car Rental system. The industrial fleet currently has

only four barge-mounted hopper dredges and no sidecaster capability (three privately owned oceangoing hoppers should be operational in 1978). Primarily, the industrial fleet is composed of 264 cutterhead, 161 clamshell, 13 dipper, and 19 hydraulic plain suction dredges. In general, the industrial fleet suffers from the same maladies as the Corps' fleet. The condition of the total dredging fleet can be traced to the great uncertainty in the dredging industry. Business is spasmodic and contractors are unwilling to undertake the financial burden of updating the dredging fleet with new equipment. With few exceptions, the National Dredging Study 27 revealed that industrial dredging organizations have not been actively involved in research and development to improve dredging capabilities and have not, until recently, built any new dredges incorporating advanced designs. In addition, the study implies that the industry is highly fragmented and has been undergoing a process of contraction and consolidation for several years. This decline in size of the industry has been caused by the high capital cost of maintaining and replacing equipment, the impact of inflation on operating and repair costs, and the restraint on dredging activities resulting from environmental restrictions. Nevertheless, an urgent need exists to modernize and replace much of the equipment in Corps and industrial inventories.

Table 4-6 summarizes the distribution by major type and geographical area of both the Corps of Engineers and the private industrial dredging fleets. A detailed inventory of all dredges in the United States is provided in Appendix C. 28

The availability of either Corps of Engineers or private dredges on short notice to the Coast Guard or other responsible agency for hazard-ous material recovery is difficult to assess. Corps dredges are generally fully committed and though dredge-owning Corps Districts would be cooperative to the extent possible, it is doubtful that a rapid response in terms of days could be mounted. The private dredging industry, on the other hand, is generally under-committed and presumably would eagerly respond in the event of a spill that required dredging. However, the need for special preparations, precise predredging surveys,

Table 4-6
U. S. Dredge Fleet Inventory: Regional Distribution

Corps Type Cutterhead Dustpan Clamshell Dipper Hopper Sidecaster Location West Coast Gulf Coast Interior Waterways Great Lakes East Coast Total

Contractor

			Туре		
Location	Cutterhead	Clamshell	Dipper	Plain Suction	Hopper
West Coast	38	53	1	0	1*
Gulf Coast	75	23	0	0	0
Interior Waterways	31	33	5	19	0
Great Lakes	23	28	4	0	3*
East Coast	97	24	_3	_0	<u>o</u>
Total	264	161	13	19	4

^{*} One on the west coast and one on the Great Lakes are trailer hopper and two on the Great Lakes are suction dredges mounted on hopper barges.

environmental impact statements, and contract negotiations may delay any actual response up to 2 months if conventional dredging practices are any indication. Moreover, private dredging industry officials may not have a full appreciation of the need for special precision, care, and precaution when dealing with hazardous materials, and thus extra supervision and coordination would be required.

4.4 ENVIRONMENTAL CONSIDERATIONS

It may be assumed that the same environmental concerns that are normally associated with dredging operations (i.e., increases in turbidity, suspended solids, and decreases in dissolved oxygen) would be present during dredging of a hazardous chemical spill, but that these concerns would be supplemented if not overshadowed by the possibility that dredging may cause resuspension and additional dispersion of significant amounts of the contaminant, even while the majority of it is being recovered. The decision to dredge should include consideration of the relative hazards to man and to the benthic and aquatic communities of leaving the contaminant in place versus the expected damage and additional hazards caused by dredging. Investigations ^{29,30,31} which have been conducted by the U. S. Army Engineer Waterways Experiment Station (WES), Dredged Material Research Program (DMRP), have studied the environmental effects caused by dredging and disposal operations. Some have dealt specifically with hazardous chemical contaminants. ³²

These studies have delineated and documented many of the environmental effects of dredging and disposal operations. The direct effects can generally be characterized as increases in turbidity, suspended solids concentration, and biochemical oxygen demand (BOD), and decreasing concentrations of dissolved oxygen and distribution of benthic organisms. Indirect effects of dredging are much more subtle and difficult to define, but are generally thought to consist of possible changes in benthic communities and changes in current flow patterns, both resulting from physical alteration of bottom topography. According to Cronin et al., 33 several major impacts occur as a result of dredging: removal of the original interface between the water and bottom sediments, which is frequently an area of high biological activity; removal

of deeper substrate material, which may provide shelter for burrowing organisms; creation of deeper substrate material, which may affect biotic populations; and release of sediments and of dissolved or adsorbed chemicals into the water. Some of these impacts are short term (i.e., increased turbidity, oxygen demand, and suspended solids), whereas others may be irreversible (i.e., changes in sediment and current flow patterns and bottom topography). Table 4-7 represents some potential temporal effects of dredging.

The type of dredge plant being used as well as the type of sediment being dredged affect the degree of adverse impacts. The concentration of suspended solids generated and increased turbidity are indicators of adverse effects on aquatic organisms. In this regard, when hazardous materials or contaminated sediments are involved, the assumption is that those dredges which cause the greatest turbidity and resuspension of solids also cause the greatest contaminant resuspension. This then must be the principal basis for assessment of the main environmental damage potential of hazardous material dredging. An additional factor that may

Table 4-7
Potential Effects of Dredging Operation

	Adverse	<u>Beneficial</u>	Short Term	Long Term
Decrease				
Dissolved oxygen	X		X	
Benthic organisms	X		X	X
Increase				
Biochemical oxygen demand	X		X	
Turbidity	X		X	
Suspended solids	X		X	
Toxic substances	X		X	X
Heavy metals	Х		X	
Change				
Sediment-water interface	Х	X	X	X
Sediment flow patterns	х	X	X	х
Bottom geometry	X	X	X	X
Benthic community structure	X	X	X	X

Note: Short term = immediate to 1 week
Long term = greater than 1 week.

be taken into consideration in selecting a dredge plant is the amount of direct destruction of benthic organisms, though it may be reasonably assumed that those organisms that may have survived the effects of the spill itself can afford to be sacrificed for the greater good of removing the offending material.

4.5 ADVANCES IN DREDGING TECHNOLOGY

4.5.1 State of the Art

As brought out earlier, the United States does not possess a state-of-the-art dredging industry, and therefore the advanced techniques discussed here, many of which could enhance the effectiveness of dredging for hazardous material recovery, would not be generally available. Until economic impetus or other considerations force the United States to employ on a large scale the innovative, technologically advanced methods and equipment found in western Europe and Japan, the ability to perform accurate, efficient dredging with minimum environmental damage will be severely limited.

Advanced dredging technologies are generally directed toward one or more of the following areas of improvement: greater depth capability; greater precision, accuracy, and control over the dredging process; higher production efficiency; and decreased environmental harm. Following are brief descriptions of the major recent innovations in production dredging that might be used to advantage in hazardous material recovery operations.

- o Ladder-mounted, submerged pumps for higher production at depths up to 200 ft.
- o Injection of buoyant material into pipe near dredging head (air and kerosene used to date) to provide increased lift and thus higher production and greater depth capability; similar in principal to airlift pumps.
- Improved designs of dredging heads to minimize material resuspension.
- o Use of spud barges (aft of the dredge) to extend hull length and increase dredge swing; will increase production efficiency of cutterhead dredges; in limited use in the U. S. today.

- o Longer ladders, connected further aft on the dredge hull to increase depth and permit greater control.
- Tandem pump systems for greater production efficiency and reliability.
- o Articulated ladder designs to maintain constant dredging head bottom contact; will allow use without damage in rougher waters.
- o Better hull designs, equipped with liquid stabilizing systems (swell compensators to allow use in heavier seas).
- Improved production instrumentation to monitor flow rates, cumulative production, etc.
- o Improved navigation, positioning, and bottom profiling instrumentation; state of the art includes advanced laser, electronic, and acoustical systems (see Chapter 5 for summary of current navigation technology).
- o Closed bucket modifications to reduce loss of fines and liquid in chamshell dredges.
- o Depth and swing indicators for mechanical dredges.
- o Clamshell to dipper convertible dredges.
- o Use of silt curtains during dredging, as well as open-water disposal, to restrict turbidity plumes, and in the case of hazardous materials, limit the added dispersion due to dredging. State of the art is in U. S., but silt curtains not in general use.

In addition to the improvements in conventional dredging discussed above, several other miscellaneous techniques and specific items of equipment deserve mencion:

- o The Amphidredge, manufactured by IHC-Holland, a major European dredge builder, is an amphibious, self-propelled vehicle that features backhoe and clamshell configurations as well as a shrouded cutterhead, similar to the MUDCAT. The Amphidredge could prove to be a most useful and versatile device against spills in small, nonnavigable streams and marshy areas.
- o A system (discussed earlier) has been developed by Takenaka Komuten Co., Ltd., of Osaka, Japan, for the dredging, treatment, chemical fixation, and land disposal of highly contaminated harbor sediments (organics, heavy metals). In this system, proprietarily named TST, a pneumatic "Oozer" dredge pumps the sediments to a sedimentation basin. The supernatant is charcoal-filtered and

returned to the harbor while the sludge is mixed with a proprietary portland cement-based additive and pumped to a disposal site where it sets. The result is claimed to be a chemically inert landfill with excellent stability and mechanical strength, capable of supporting heavy construction. This system could probably be made available in the U. S. given a sufficient lead time. Though it cannot be considered a response system, it does address all phases of the hazardous material clean-up problem.

o A special dredging head named "Cleanup" has been developed in Japan to be used with standard hydraulic suction dredges for cleaning up highly contaminated sediments with a minimum of turbidity and hazardous material resuspension and optimum dredging accuracy. It consists of an articulated box that completely encloses the suction head and allows water to be entrained and mixed from one direction only. It is highly instrumented in order to ensure a constant cutting depth and slurry density, and it features a trap to capture noxious gas bubbles that are released as the sediment is disturbed. Results of demonstrations have shown that turbidity and chemical oxygen demand (COD) in close proximity to the cleanup head are virtually the same as that of the undisturbed ambient water.

4.5.2 New Concepts in Dredging

Most of the conceptual thinking taking place in the dredging field continues to address the problem of increasing efficiency, production rates, and effective dredging depths along with considerable new interest in developing ways to mine the deep oceans for manganese nodules. Little thought, other than what has been discussed, seems to be directed toward hazardous material recovery. Mitigation of the adverse environmental effects of dredging and particularly of dredged material disposal continues to be of interest to the environmentally aware public and to the Corps of Engineers through the DMRP, but few engineering advances in dredging equipment and technology are on the horizon.

For purposes of enhancing the potential of dredging as a response to spills of hazardous materials that sink, the following areas of inquiry are likely candidates that need thought, basic research, development, or demonstration.

o Designs of dredging heads and improved techniques for better and more efficient control of sediment resuspension. Study and demonstration of existing ("Cleanup") devices.

- o Study and characterization of interaction of selected spilled hazardous materials with various sediments in various aquatic and marine environments.
- o Dispersion behavior in various bottom environments of various solid and liquid chemicals that sink.
- o Devices and instruments for in situ detection of various types of contaminants in bottom sediment, possibly on board recovery dredges.
- o Development of a floating storage/treatment system for contaminated dredged material.
- o Development of an epoxy or teflon-lined pneumatic dredging system, with optional CO₂ working gas, for recovery of corrosive and/or flammable chemicals.

4.6 DREDGE SYSTEM EVALUATION

In this section each basic type of dredge is evaluated as to its overall potential for hazardous material recovery in each of the four general environmental settings established in Chapter 3. The numerical ratings are presented in four matrices, one for each setting (Tables 4-8 through 4-11). The column headings correspond to job size compatibility (not spill size) and to those site-specific factors identified in Chapter 3 as likely to be critical in each setting and that are at the same time amenable to at least a qualitative numerical rating. Each major type of dredge is assigned a numerical score from 0 (worst) to 10 (best) for each of the rating criteria. Each of the rating criteria is assigned a weighting factor in accordance with its relative importance in influencing the suitability of dredges in each of the four spill settings. Finally, a weighted average is computed to arrive at a score between 0 and 10 for each dredge in each spill setting. The weighted average score should be viewed as an overall indication -- not an absolute measure--of the dredge's potential for use in a given setting; dredges with higher scores may typically do a better, faster, or more complete job with less harm to the environment, based on the criteria used, than those with lower scores. The particular circumstances present at an actual spill site would, of course, have to be examined and weighed

Table 4-8

Dredge Evaluation Matrix*

Spill Scenario: Land and Nonnavigable Waters - All Spill Sizes

	Job	Job Size Compatibility	thility								
	Small <1000	Medium 1000 -	Large >200,000		Resuspension	Debris and	Transportation/	Ove	Overall Potential	181	
	cu yd	200,000 cu yd	cu yd	Solids	of Sediments and Contaminants	Structural Obstacles	Mobilization Time	Small Yardage	Medium	Large	Notes
Weighting Factor	2	5	5	1	2	1	2	NA	NA	AN	W
Mechanical	NA	NA	NA	NA NA	NA	NA NA	AN	NA	NA	NA.	N.
Dipper Clamshell				SETTING NO	(SETTING NORMALLY INACCESSIBLE TO THIS TYPE EQUIPMENT)	TO THIS TYPE	EQUIPMENT)				
Hydraulic	NA	NA	NA.	W	NA	NA NA	Ä	NA.	NA	¥	NA
Cutterhead (and plain suction) Dustpan Hopper				SETTING NO	(SETTING NORMALLY INACCESSIBLE TO THIS TYPE EQUIPMENT)	TO THIS TYPE	EQUIPMENT)				
Pneumatic	9	80	•	~	1	1	8	5.8	6.7	5.8	a,b,c
Other											
MUDCAT	6	7	2	9	9	4	7	7.4	6.5	4.2	
Handheld Vacuum	2	3	0	2	6	6 0	80	6.3	5.4	4.0	a,c,d
Land-based, Earth-Loading Equipment	•	6	6	10	2	œ	٥	7.7	7.7	7.7	a

Notes.

Plain suction will be effective only in free-flowing sediments such as sands, unconsolidated silty, clayey, or organic sediments, and liquids. Pneumatic systems which are normally operated in a plain suction mode could be operated with a variety of suction head devices such as augers

and cutters.

Equipment can be land-based and operated from shore or pier, as well as from barge-mounted configurations.

Handheld vacuum will seldom be suitable as a first line recovery device due to extremely limited production capacity. Probably will be most useful for precise cleanup and peripheral operations; in situations of small, concentrated, well-defined spills; and for cleanup in close

Includes such equipment as backhoes, front-end loaders, dozers, draglines, and shovels varying in size from small farm tractor-mounted to large atrip-mining equipment.

INDITION OF THE INFERICAL SCORES REFLECTED IN THIS TABLE SHOULD NOT BE CONSTRUED AS AN ABSOLUTE MEASURE OF THE DREDGE'S VALUE

Spill Scenario: River - All Spill Sizes Dredge Evaluation Matrix* Table 4-9

	Job	77	tibility		Resuspen- sion of						Trans-				
	Small	Medium 1000 -	Large >200,000		Sediments	Dredging Depth	Vessel Draft	Debris	Hin- drance	Current	Mobili-	Over	Overall Potential	rial	
	cu yd	200,000 cu yd	cu yd	Solids	Contami- nants	Limita- tion	Limi- tation	Structural Obstacles	to Traffic	Limita- tions	zation Time	Small	Medium	Large	Notes
Factor	9	9	9	1	3	1	7	2	1	1	2	NA.	W	NA	N
Mechanical															
Dipper	1	5	1	10	1	4	80	1	7	9	4	8.8	5.2	3.9	a,b,c
Clamshell	80	•	7	10	1	10	80	6	7	9	4	9.9	6.0	4.7	a,b,c
Hydraulic															
Cutterhead (and Plain Suction)	e - a	-	•	'n	~	٠	~	e	e	7	7	4:1	5.4	6.0	d,e,f
Dustpan	3	7	80	2	2	9	1	3	3	7	2	4.1	5.4	5.7	J
Hopper	3	1	1	2	2	9	7	1	•	6	4	4.0	5.3	5.3	•
Pneumatic	•	1	4	1	1	10	1	6	6	9	5	9.9	6.9	5.9	c,d,8
Other															
MUDCAT	6	2	2	9	9	3	6	4	5	4	80	7.0	5.7	4.7	4
Handheld Vacuum	5	-	0	7	•	•	10	10	•	-	6	8.9	9.6	5.3	c, d, 1
Notes:															

Ineffective against liquid contaminant unless known to be strongly adsorbed in the sediment. Pure mechanical devices will be relatively ineffective on hard rock or hardpan clay sediments.

Equipment can be land-based and operated from shore or pier, as well as from barge-mounted configurations.

Plain suction will be effective only in free-flowing sediments such as sands, unconsolidated silty, clayey, or organic sediments, and liquids. Cutterheads should be turned off when operating in a rock or hardpan bottom to avoid unnecessary dispersion of contaminant and/or damage to

dredging equipment. Dredging depths can be effectively increased with the addition of auxiliary booster pumps at the suction head. Pneumatic systems which are normally operated in a plain suction mode could be operated with a variety of suction head devices such as augers and

MUDCAT cannot be used in most open-water situations due to severe depth and wave height limitations, but probably would be most effective in

small, nonnavigable streams.
Handheld vacuum will seldom be suitable as a first line recovery device due to extremely limited production capacity. Probably will be most useful for precise cleanup and peripheral operations; in situations of small, concentrated, well-defined spills; and for cleanup in close quarters.

THE NUMERICAL SCORES REFLECTED IN THIS TABLE SHOULD NOT BE CONSTRUED AS AN ABSOLUTE MEASURE OF THE DREDGE'S VALUE

Spill Scenario: Ports and Harbors - All Spill Sizes Dredge Evaluation Matrix* Table 4-10

	Job S	Size Compa	tibility		Resuspen- sion of					Trans-				
	Sma11 <1000		Large >200,000		Sediments	Dredging Depth	Vessel Draft	Debris	Hin- drance	Mobili-	Over	Overall Potential	tial	
	cu yd	200,000 cu yd		Solids	Contami- nants	Limita- tion	Limi- tation	Structural	Traffic	zation	Small	Medium	Large	Notes
Factor	5	5	5	-	1	1	-	2	1	1	NA	NA	NA NA	NA
Mechanical														
Dipper	1	5	1	10	1	4	6	7	80	5	9.9	5.9	4.3	a, b, c
Clamshell	80	9	-	10	-	10	6	6	80	2	7.8	7.0	5.1	a, b, c
Hydraulic														
Cutterhead (and Plain Suction)	e	-	•	5	'n	•	œ	e .	4	e	0.4	5.5	6.3	d,e,f
Dustpan	3	1	80	2	2	9	80	3	4	3	4.0	5.5	5.9	4
Hopper	3	1	1	2	S	9	2	1	6	4	3.9	5.5	5.5	ų.
Pneumatic	9	1	4	7	7	10	80	•	4	8	6.9	7.2	6.1	8,b,2
Other														
MUDCAT	6	5	2	9	9	1	6	4	2	80	8.9	5.2	4.1	_E
Handheld Vacuum	5	1	0	7	•	•	10	10	7	6	8.9	5.2	6.4	c,d,1
Notes:														-

Ineffective against liquid contaminant unless known to be strongly adsorbed in the sediment.

Pure mechanical devices will be relatively ineffective on hard rock or hardpan clay sediments.

Equipment can be land-based and operated from shore or pier, as well as from barge-mounted configurations.

Plain suction will be effective only in free-flowing sediments such as sands, unconsolidated silty, clayey, or organic sediments, and

liquids.

Cutterheads should be turned off when operating in a rock or hardpan bottom to avoid unnecessary dispersion of contaminant and/or damage to dredging equipment.

Dredging depths can be effectively increased with the addition of auxiliary booster pumps at the suction head.

Pheumatic systems which are normally operated in a plain suction mode could be operated with a variety of suction head devices such as

MUDCAT cannot be used in most open-water situations due to severe depth and wave height limitations, but probably would be most effective in augers and cutters.

small, nonnavigable streams. Handheld vacuum will seldom be suitable as a first line recovery device due to extremely limited production capacity. Probably will be most useful for precise cleanup and peripheral operations; in situations of small, concentrated, well-defined spills; and for cleanup in close

THE NUMERICAL SCORES REFLECTED IN THIS TABLE SHOULD NOT BE CONSTRUED AS AN ABSOLUTE MEASURE OF THE DREDGE'S VALUE

Spill Scenario: Open Waters - All Spill Sizes Dredge Evaluation Matrix*

	Job S	ize Compa	tibility										
	Small <1000	Medium 1000 -	Large >200,000		Resuspension	Dredging Depth	Hin- drance		Transportation/	Over	Overall Potential	141	
	cu yd	200,000 cu yd	cu yd	Solids	of Sediments and Contaminants	Limita- tion	to Traffic	Wave	Mobilization Time	Small Yardage	Medium	Large	Notes
Weighting Factor	00	80	80	1	1	4	1	4	1	NA	NA	NA	NA
Mechanical													
Dipper	1	5	1	10	1	4	4	4	4	5.4	4.6	3.0	a,b
Clamshell	80	9	1	10	-	10	4	2	4	7.2	4.9	4.4	a,b
Hydraulic													
Cutterhead (and Plain Suction)	9	1	•	~	s	•	4	4	r	4.1	5.7	6.5	c,d,e,f
Dustpan	3	1	•	2	5	9	4	4	3	4.1	5.7	6.1	a
Норрег	3	1	1	2	2	9	6	10	9	5.7	7.3	7.3	e , f
Pneumatic	9	1	4	1	7	10	4	2	2	9.9	7.0	5.8	8,2
Other													
MUDCAT	6	2	2	9	9	1	4	1	80	5.2	3.6	2.4	e.
Handheld Vacuum	0	-	0	2	•	9	1	œ	6	6.2	4.6	4.2	1 5
N. P. P. P.													-

to Ineffective against liquid contaminant unless known to be strongly adsorbed in the sediment.

Pure mechanical devices will be relatively ineffective on hard rock or hardpan clay sediments.

Plain suction will be effective only in free-flowing sediments such as sand and liquids.

Cutterheads should be turned off when operating in a rock or hardpan bottom to avoid unnecessary dispersion of contaminant and/or damage dredging equipment. Dredging depths can be effectively increased with the addition of auxiliary booster pumps at the suction head.

Swell compensators can increase ability to operate in higher wave environment.

Pneumatic systems which are normally operated in a plain suction mode could be operated with a variety of suction head devices such as augers and cutters.

MUDCAT cannot be used in most open-water situations due to severe depth and wave height limitations, but probably would be most effective in small, nonnavigable streams.

Handheld vacuum will seldom be suitable as a first line recovery device due to extremely limited production capacity. Probably will be most useful for precise cleanup and peripheral operations; in situations of small, concentrated, well-defined spills; and for cleanup in close quarters. THE NUMERICAL SCORES RELECTED IN THIS TABLE SHOULD NOT BE CONSTRUED AS AN ABSOLUTE MEASURE ON THE DREDGE'S VALUE

against the capabilities of specific candidate dredges before a final decision could be made. The last column notes certain qualifications, limitations, and other points that deserve special mention, but are not reflected in the ratings themselves.

The dredge evaluation matrices do not consider or attempt to quantify the possible influence of chemical-specific considerations on dredge selection. Dredging to remove hazardous chemicals from the bottom is principally a material relocation problem and the particular chemical spilled does not add significantly to the problem (with several notable exceptions pointed out in Chapter 2) of assessing the suitability of a dredging technique. The same disadvantages are usually present (e.g., resuspension of the contaminant) regardless of the particular contaminant. However, precautionary measures (Chapter 2) appropriate to the specific chemical being recovered should always be diligently observed. Additionally, the ratings do not directly take into account the problems of dredged material transport, treatment, and disposal—factors which may frequently be found to be controlling in selecting a system.

The individual rating criteria used in the evaluation matrices are defined and discussed below.

4.6.1 Job Size Compatibility

As discussed briefly in Chapter 3 (Spill Scenarios), the total volume of contaminated bottom material to be dredged—not the actual volume of chemical spilled—is the prime consideration (and also the most heavily weighted) in each matrix. The reason that spill size per se cannot be used in a dredging assessment is that under conditions favoring rapid dispersion, a small spill (<1000 gal) might easily translate into quite a large dredging job (>200,000 cu yd), in which case the average contaminant concentration, in situ, would be about 25 ppm and perhaps five times more dilute in the dredge discharge pipe. Conversely, it would not be unreasonable to expect, in quiescent, shallow water or on land, for a large chemical spill (>50,000 gal) to result in a small dredging job (<1000 cu yd). The contaminant concentration of the in situ sediment in this example would be about 25 percent by volume. In order

to properly choose a dredge for a job, the amount of material to be excavated must be estimated in advance. To be compatible with a given job size a dredge must have sufficient production capacity to be capable of completing the job in a reasonable time frame (days or weeks—certainly not years), but not such a large capacity that all cost-effectiveness is lost through overkill. This is the rationale for the ratings under the job size compatibility criterion. Each dredge is scored for compatibility with the arbitrarily defined small, medium, and large job sizes and therefore will have three overall scores, one for each job size category.

4.6.2 Solids Content

No standard, universally accepted definition of solids content exists in the dredging industry; however, the term generally refers to the relative amount of solid material (percent by volume or weight) contained in the water-sediment slurry. Higher solids contents are considered more desirable since this implies that a greater percentage of bottom material has been excavated for a given volume of slurry to be disposed of. Usually ranging between 10 and 30 percent by weight, solids content at a given site depends on the nature of the sediment, the skill of the dredge operator, and the characteristics of the dredge. For a given sediment and dredge operator, one dredge type may be capable of yielding denser (higher solids content) slurries than another -- the basis for this rating criterion. When applied to the dredging of hazardous materials or contaminated sediments, it is assumed that higher solids contents correspond directly to higher concentrations of contaminant in the dredged material and therefore higher contaminant recovery rates. (An exception is the case of an intact pool of liquid contaminant not adsorbed in the sediments.) The dredges that are capable of producing the densest material receive the highest scores. The solids content criterion carries a weighting factor of one, indicating its relatively minor importance compared to other factors.

4.6.3 Resuspension of Sediments and Contaminants

It is assumed that the quantity of hazardous material resuspended during a dredging operation is approximately proportional to the amount of sediment resuspended and/or turbidity caused. Ratings are based on qualitative observations and relative comparisons among various dredge types; extensive research is badly needed in this area. The relative weight assigned to this criterion in a given environmental setting depended on the likely degree of concern and probable adverse impact of hazardous material resuspension during recovery in that setting. In rivers and nonnavigable streams where currents would carry resuspended material downstream to previously unaffected areas, resuspension would be a major consideration. Conversely, in ports and harbors where human consumptive use is less likely, where there may be fewer aquatic species of commercial value, and where relatively quiescent conditions would prevent wide dispersion of resuspended material, resuspension would normally be of less concern. In open waters the greater dilution potential and the probable absence of human consumptive use again makes this consideration less critical.

4.6.4 Dredging Depth Limitation

At an actual spill site the water depth will either allow the use of a particular dredge or preclude its use; such a determination must, of course, be made in each case. For purposes of rating dredges on working depth as part of an overall suitability score, it was necessary to assign a score of 10 to those dredges with no theoretical depth limit (clamshell, Pneuma), a low score to those with severe depth limitations (MUDCAT), and an intermediate score to those with intermediate depth capabilities (conventional hydraulic dredges). The importance of water depth as a consideration in the overall score increases in the settings where the water depths may approach the limit of one or more types of dredges. Thus, in the open-water setting where deeper waters generally prevail, this criterion receives a high weighting factor (4). In the river and harbor settings, except for unusual circumstances, the

depth will normally allow the use of any type of dredge and thus the depth criterion carries a low weight factor (1). In the land and non-navigable water setting, depths too great for any of the dredges would probably never occur; thus, the criterion does not even appear in that matrix.

4.6.5 Vessel Draft Limitation

This criterion complements the previous one in that in some cases the water in which the dredging operation will take place will be too shallow to accommodate the vessel mounting the dredge. In the open water and ports and harbors settings the depth will normally (but not necessarily always) be sufficient to accommodate any dredge vessel (deep draft vessels such as hopper dredges would receive lower scores). The relative weighting factor for draft limitations in these deeper settings is thus low (1). In the river setting it is surmised that shallow water will be a somewhat more frequent problem, thus a higher weighting factor is assigned (2). In the land and nonnavigable water setting this consideration is so decisive that rather than include it with a ridiculously high weighting factor, any dredge type whose hull normally has a draft greater than 3 ft was eliminated from consideration at the beginning.

4.6.6 Debris and Structural Obstacles

This criterion addresses the effect of submerged and surface debris (logs, large outcroppings, scrap metal, sunken boats, cars, etc.) and man-made structures (bridge piers, docks, wharves, weirs, pipelines, cables, etc.) on the proper and efficient operation of the various dredge types. These types of obstacles naturally tend to be of greater concern where their density is high, as in ports and harbors and along navigable rivers and waterways. In these two settings, therefore, this criterion warrants a higher weighting factor (2) than in the others (1). Individual dredge types are scored according to their ability to work normally around and among such obstacles.

4.6.7 Hindrance to Traffic

In contrast to the previous criterion which deals with how objects hinder dredging operations, this criterion is concerned with how dredging operations hinder the normal flow of waterborne traffic. It is recognized that in the event of a spill recovery operation, a temporary shutdown of shipping and barge traffic can and probably will occur; this is a common occurrence during low flows on major river arteries when emergency channel dredging takes place. However, some dredge types are more "in the way" than others and, as a potential discriminator, this fact should be accounted for in the overall scores. Generally, the hydraulic pipeline dredges, including the pneumatic systems and the MUDCAT, operate at a comparative snails pace with a network of cables and mooring lines and a pontoon-supported floating pipeline from the dredge to the shore or a storage scow. In short, these dredges are very much in the way and receive lower scores than the mechanical dredges or the hopper dredges. The latter are ideally suited for dredging in shipping lanes without disrupting traffic.

4.6.8 Wave Height

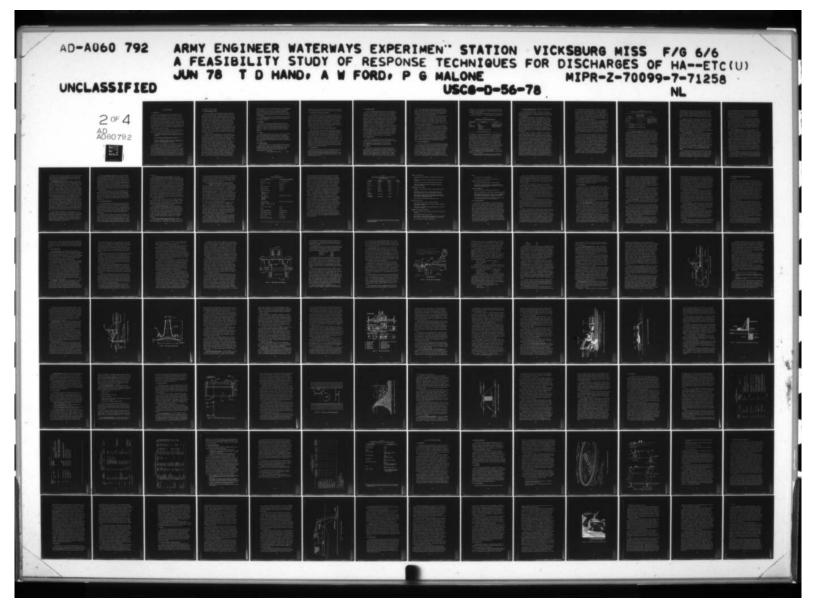
The only environmental setting in which wave height would be a significant consideration in discriminating among dredges is the open-water setting, but in this setting it is a major factor and warrants a high weighting factor (4). This criterion is not included in the other settings. Barge-mounted dredges are generally limited to seas of 3 or 4 ft unless they are equipped with swell compensators and other devices that increase their tolerance to rough water; however, such modifications have yet to find their way in any significant degree into the American dredging fleet. MUDCAT dredges would be swamped in 3-ft seas. Handheld devices, operated underwater by a diver, could be used in any wave condition that the supporting vessel can tolerate. Hopper dredges are oceangoing vessels designed for use in rough waters and receive the top rating in this category.

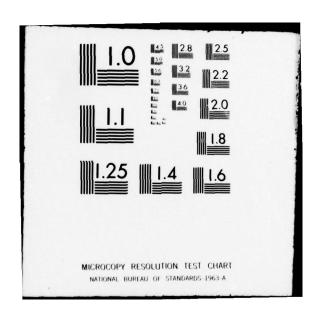
4.6.9 Current Limitations

Precise information on the sensitivity of dredging vessels to strong currents is not available, but depending on size, weight, balance, and the propulsion and anchoring system, the limiting current velocity for barge-mounted systems is in the 4- to 6-knot range. Hopper dredges are self-propelled, streamlined, oceangoing vessels and can operate in somewhat faster currents. MUDCAT dredges would be more sensitive to currents than larger barge-mounted plants; divers wielding suction hoses would be the most limited by currents. As a discriminating factor, current cannot be ignored where it has the potential to influence the operation, as in river situations, yet in comparison with other criteria it is relatively minor and therefore carries a weighting factor of 1. In the land and nonnavigable stream, open water, and ports and harbors settings current is not considered important enough to play a decisive role and is not included.

4.9.10 Transportation/Mobilization Time

The ratings under this criterion are an attempt to bring together and quantify a number of related but elusive considerations. Taken as a whole the individual ratings seek to answer the question: "How quickly could a dredge of this type be placed in operation at the scene of the spill?" The component considerations include: ease of transport over long distances (air, rail, truck); ease of moving from berth or present site to spill site in given setting; probable need for custom modifications; likelihood of type dredge being available and in suitable proximity; and time required for contract negotiations, environmental impact statements, etc. The actual scores are based on the consensus judgment of the authors in light of information available on the above considerations. The weighting factor given to this criterion is based on the need for urgency in a given setting, with rivers and land and nonnavigable waters requiring more urgency than open waters and ports and harbors due to the greater potential for serious environmental or humar harm in delaying.





5.0 BURIAL TECHNIQUES

5.1 INTRODUCTION

Burial of a spilled chemical, as the sole measure taken, will seldom be the best or most desirable response. It must be recognized that sooner or later, despite all efforts to prevent it, any covering layer may be reexcavated naturally by scouring, biological action, or both, especially in settings where storms, floods, unusual tides, etc., can produce extreme currents and turbulence. It must also be noted that burial would be a patently inappropriate response for a chemical spilled in a shipping channel that must be routinely dredged to remain open. As pointed out in Section 2.3 and as reflected in the "Recommended Response" column of Tables 2.1 and 2.2, for most of the 70 chemicals in most circumstances the best response is removal.

Nonetheless, burial as a response can fulfill a number of appropriate roles, and a feasibility assessment of the various techniques will be of value. Appropriate roles of the burial response include:

- o As a temporary mitigating measure to retard the spread or reduce the hazard of a spill until a recovery (dredging) operation can be mounted.
- o As a final step, following the recovery of most of a spill, to isolate any residual contamination of the sediments.
- o As the sole response when recovery cannot be accomplished or in cases where the spilled chemical is harmless or nearly so (see Section 5.2 "Chemicals Amenable to Burial").

In this chapter, the assessment of burial techniques will consist of the following: a short discussion of the chemicals most amenable to burial, intended to amplify the information presented in Chapter 2, Chemical Considerations; a section in which the suitability of a number of selected burial materials is assessed; a section in which a number of existing and conceptual emplacement methods are suggested and assessed; and a final section containing a table that summarizes the burial materials that are compatible with each hazardous chemical under consideration and a matrix in which each potential emplacement method is numerically

rated against each spill scenario.

5.2 CHEMICALS AMENABLE TO BURIAL

Early in this program, it was decided that liquids were generally not suited to covering or burial. Even dense, viscous liquids such as PCB's can logically be expected to disperse when impacted by materials intended to bury them. The most likely candidates for burial were therefore limited to solid chemicals; however, it should be kept in mind that any hazardous chemical on the bottom of a water body will disperse to some extent. At the periphery of the dispersion pattern, the spilled substance will have no physical character of its own, either liquid or solid; its presence in the bottom sediment will be definable only by chemical analysis. Such perimeter areas, whether resulting from a liquid or solid chemical spill, may be amenable to burial even though the center of the spill must be treated otherwise. In that sense, burial should be considered at least a partial option for any spilled hazardous chemical that sinks. This is the rationale for the second role of burial stated in the previous section.

In Chapter 2, Chemical Considerations, it was concluded that only those chemicals that are essentially harmless or whose reaction products after burial with a chemically active material are harmless should be considered as candidates for burial as a first-choice response. Of the 70 materials under study only the 3 asphalts, sulfur, and barium carbonate can be considered to meet this condition fully. Several additional solid materials, which are moderately hazardous in an aquatic environment, could be rendered significantly less so by proper burial when removal -- the best alternative -- is not possible. These chemicals are aluminum fluoride, calcium fluoride, calcium oxide, calcium hydroxide, calcium carbide, and lead arsenate. Finally, there are two materials -red and white phosphorus -- that are very hazardous to aquatic life if left in place, but possibly even more hazardous to human life if their recovery were attempted. Depending on specific circumstances burial with a reactive material may be the best response. (See discussion below.) Several other solid materials would be extremely hazardous to

dredge or recover due to their explosive nature (e.g., 2,4 Dinitroaniline; 2,4 Dinitrophenol), but it is felt by the authors that they are sufficiently hazardous to the environment that recovery is nevertheless mandatory. All remaining solids on the list are quite toxic, or otherwise hazardous, but offer no chemical barrier to recovery and therefore should be removed.

The following paragraphs briefly characterize those chemicals cited above as being amenable to burial, either as a first choice response or as a second or last resort.

5.2.1 Asphalts

The asphalt fraction that sinks should be buried with an inert covering to prevent its being moved around by currents or tides. The covering will also help to retard the slow microbiological attack of the asphalt mass. Asphalt is an ideal candidate for burial, because its toxicity is not great and because it would be difficult to recover by dredging.

5.2.2 Sulfur

The primary hazard caused by a sulfur spill is related to the spill event itself, when molten sulfur enters the water. After sinking, plastic sulfur may be slowly acted upon by bacteria to release sulfuric acid. An inactive covering material will, as in the case of asphalt, retard this phenomenon. A basic material may be added to neutralize any acid produced.

5.2.3 Barium Carbonate

Barium ions are quite toxic. However, barium sulfate is virtually insoluble in water. Hence, it is relatively nontoxic. An active covering material which contains sulfate (e.g., calcium sulfate, ferric sulfate) should be used to cover the barium carbonate spill. The following reaction will take place:

$$CaSO_{L} + BaCO_{3} + BaSO_{L} + CaCO_{3}$$
 (5-1)

Seawater may contain enough sulfate to precipitate barium. An inactive covering material would retard diffusion of barium from the spilled mass.

5.2.4 Aluminum Fluoride and Calcium Fluoride

The toxicological problem with each of these compounds is with the release of fluoride. Because these two substances are among the most insoluble of the fluoride compounds, covering with an active covering that would chemically convert the spilled mass to a more insoluble state is unlikely. An anion exchanger is a possibility, but not in seawater where the chloride would compete with the fluoride. An inert covering material could be used to retard the diffusion of fluoride from the spilled mass to the water column. Each of these compounds would tend not to change chemical form in the aquatic environment.

5.2.5 Calcium Hydroxide, Calcium Oxide, and Calcium Carbide

When calcium oxide or calcium carbide are spilled into water they form calcium hydroxide exothermally. (The calcium carbide reaction also releases highly flammable acetylene gas.) Calcium hydroxide is quite caustic and since a saturated solution of this compound has a pH of 12.4, it is also quite toxic. An active covering agent should be able to neutralize the caustic material (i.e., the agent should be acidic). Also, if iron or aluminum ions were available, they would react with the hydroxide to form hydrous oxides. An inert cover could be used to retard diffusion of hydroxide from the spilled mass. However, this will not mitigate the caustic mixing zone created by the actual spill. Calcium hydroxide will react with sulfates and carbonates (carbon dioxide) which are common to most aquatic environments.

5.2.6 Lead Arsenate

Both the lead and arsenic portions of this compound are poisonous. This material should generally be recovered to prevent its toxic release. Because the compound is soluble in acid conditions, an active covering material which has basic properties would be desirable if the covering alternative is used.

5.2.7 Phosphorus, White

This is an extremely dangerous material since it self-ignites in moist air at 30°C. The principal manufacturers of elemental phosphorus are Monsanto and FMC Corporation. They maintain their own response capability in case of a spill and prefer to be called in to handle any and all response efforts. They normally attempt to recover the material under water. If burial is necessitated, an active agent, gently placed, should be selected to convert the phosphorus from its elemental form as quickly as possible. These might include sulfur, pyrites, and solid oxidizing agents such as potassium permanganate to help oxidize the phosphorus in situ. Inert covering should not be used because the phosphorus is so toxic. It is important to avoid stirring up the spilled phosphorus in a colloidal form. A phosphorus spill, as in the case of most of the organics, will cause a fish kill. As long as the elemental phosphorus remains in the aquatic environment, organisms will continue to die. While phosphorus is very hazardous to the aquatic environment and very hazardous to recover, balancing the hazards must be done on a case-by-case basis; at times covering will be the response of choice because of hazards to personnel involved in recovery efforts.

5.2.8 Phosphorus, Red

Very little of this material is shipped. It may explode with friction. An active covering material may be useful; response techniques should generally be similar to those for white phosphorus.

5.3 IDENTIFICATION AND CHARACTERIZATION OF BURIAL MATERIALS

5.3.1 General

Several materials, both naturally occurring and man-made, that could be used to cover submerged spills of hazardous chemicals have been identified and divided into four categories for discussion: inert, chemically active, chemical additives, and sealing agents. Chemical additives are those compounds that can be added to any of the other types of cover to enhance their effectiveness in specialized applica-

tions. Inert and chemically active materials will be discussed in detail in this chapter (Task III) with detailed discussion of chemical additive and sealing reserved for Chapter 6 (Task IV). However, preliminary discussion of the latter two groups of covering agents will be presented in this section where appropriate.

Initial identification of potential covering materials was accomplished through a search of the literature. Much of the literature available on covering and burial stemmed from work related to mercury contamination performed in the late 1960's and early 1970's. Though mercury is not considered in this report as a likely candidate for burial, much of this earlier work has general value. A review of this literature is included as Appendix D.

Characterization of covering materials will include discussions of the chemical nature of the material (where applicable); the ability of the material to retard leaching into the water column; susceptibility of the cover to scour; potential impacts on biota; and cost and availability. In this regard, grain size will be an important parameter as it has a significant effect on both leaching retardation and susceptibility to scour and resuspension. The approach to be taken is to discuss inert covering materials first, followed by a discussion of chemically active materials. These two categories will be discussed in depth. Chemical treating agents and sealing/grouting agents will be listed, with detailed discussions of these reserved for Task IV.

5.3.2 Inert Covering Materials

In Section 5.2 the use of an inert covering material was suggested to retard leaching into the water column. Previous work on the covering of in-place pollutants has frequently alluded to the use of inert substances in experimental covering. Depths of 10 cm were considered by Jernelov to be capable of inhibiting certain biological activity which might contribute to leaching into the water column. Pratt and O'Connor suggest benthic activity to be a limiting factor to consider in determining covering depths, with some species surviving a 20-cm burial. Covering depths, then, should probably be in this range

(equivalent to a 4- to 8-in. cover) to inhibit leaching due to biological activity. Cover thickness must be considered site specific, however, depending on the local benthos.

A list of potential inert covering materials has been developed and is presented here as Table 5-1. Two broad categories of inert materials

Table 5-1

Generalized List - Inert Covering Materials

Coarse-grained	Fine-grained	Mixtures
Gravel Sand Crushed Stone Crushed Glass	Clays: Kaolin Bentonite Fuller's Earth Ball Clay Fire Clay Miscellaneous Clays (local)	Any combination of these materials, including dredged material and deliberate mixtures
	Diatomaceous Earth/Filter Aid	

are identified: coarse-grained and fine-grained. Coarse-grained materials include sand, gravel, crushed stone, etc. Fine-grained materials include commercially available clays (often used as soil sealants), diatomaceous earth, and other materials. It is recognized that transition materials of silt-like grain size exist and will combine many of the properties associated with fine-grained and coarse-grained sediments. Dredged material was included as a separate category because of both its variability in predominant grain size from location to location and the ease with which it can be obtained. Grain-size distribution and pollutant loads will be site specific, but nearby availability of in situ covering material is assumed regardless of the spill location.

- 5.3.2.1 Susceptibility to Scour and Resuspension. Erosion of the bottom of a waterway with spilled hazardous chemicals on the bottom may be of concern for two reasons:
 - a. Covering materials that have been placed on the spilled chemicals may be removed, thereby frustrating attempts at burial.

<u>b</u>. The spilled chemical itself, or sediments contaminated by them, may be eroded and dispersed.

The second effect would, of course, not occur if the covering material can be prevented from scouring. Therefore, it is the erosion of the burial material that is of primary concern and the subject of the following discussion.

Susceptibility of a sediment to scour will depend on: (1) the particles (size, uniformity, shape, size distribution, texture, etc.); (2) the dynamics of flow; (3) slope of the bottom; (4) angle of repose of the particles; and (5) the degree of cohesiveness of a particular sediment. Thus, predicting scour and resuspension tendencies of such covering materials cannot be made in a general sense. Unfortunately, most of the available literature applicable to this subject is concerned only with natural materials (sand, silt, and clay). Application of erodibility considerations to the many man-made or man-emplaced burial materials discussed in this report is consequently based on theory and extrapolations.

From the viewpoint of erodibility, sediment used for covering may be generally classified as cohesive or noncohesive. As the term implies, noncohesive sediment consists of discrete particles the movement of which, for given erosive forces, depends only on particle properties, such as shape, size, and density, and on the relative position of the particle with respect to surrounding particles. For cohesive sediments, the resistance to any movement or erosion depends on those factors cited above for noncohesive sediment as well as on the strength of the cohesive bond between particles. This latter resisting force may be much more important than the influence of the characteristics of the individual particles. Because the water currents required to erode or scour cohesive sediments are generally greater than those for noncohesive sediment with approximately the same grain size, the rate and extent of scour depends on this property (cohesive strength) rather than on the properties of the individual particles. Once the cohesive bond has been broken, the individual particles behave as noncohesive particles for which deposition, scour, and transport become functions of the properties of the separate particles or small groups of particles. Additionally, once resuspended, the hydrodynamic behavior of cohesive sediments is complicated by the effects of flocculation. Floc size distribution depends not only on the physiochemical properties of the particles, but also on the flow conditions themselves. This dual dependence makes the processes of erosion, transport, and deposition of fine (cohesive) sediment fundamentally different from and considerably more complex than similar processes for noncohesive sediment.

Investigations 36-39 have also shown that for fine-grained sediments in particular the degree of consolidation--inversely proportional to the interstitial water content--has a significant effect on the ease with which they will erode. Whereas recently deposited (unconsolidated) clays would be among the most easily resuspended sediments, aged (well-consolidated) clays may be among the most resistant materials to scour, approaching the stability of course gravel. The time required for essentially complete consolidation to take place can range from minutes for coarse-grained deposited materials to hundreds of years for fine clays.

An in-depth discussion of the findings of related research studies that have been conducted and their application to burial of hazardous material spills is too lengthy and detailed to be included here in the main text, but is given in Appendix E. This discussion brings out the fact that the subject of scour and resuspension of sediments defies generalization. However, for guidance of those who must base important spill response decisions on available information, Table 5-2 is presented as a qualitative guide to erosion and resuspension potential of various possible inert cover materials. In the subsequent section on active covering materials, similar considerations are presented.

The need for accurate data on currents at the spill site cannot be overemphasized. For example, if consolidation of a cover is desired, knowledge of seasonal or storm-induced high currents is necessary to assess the likelihood of scour during the consolidation period.

Table 5-2
Tendencies of Natural Inert Sediments to Erode

Material	Erosion	te Range of Velocities (ft/sec)	Mixtures
Coarse Sand/Gravel	40 - 300	(1.3 - 9.8)	Depends on grain-size distribution and miner-
Medium Sand	20 - 40	(0.7 - 1.3)	alogy of fines, but generally more stable
Fine Sand	20	(0.7)	than covers of uniform grain size.
Silt - Consolidated	30 - 70	(1.0 - 2.3)	
Unconsolidated	10 - 20	(0.3 - 0.7)	
Clay - Consolidated	50 - 300	(1.6 - 9.8)	
Unconsolidated	5 - 15	(0.2 - 0.5)	

5.3.2.2 Ability to Retard Leaching. Leaching of pollutants through cover material is expected to be directly related to grain size: the larger the grain size, the more leaching that will occur. Pratt and O'Connor have developed a mathematical model of a sand cover placed over polluted dredged material at a disposal site. The model allowed heavy metals to migrate through the cover and followed the total heavy metal load as a function of depth and time. The model is essentially a one-dimensional diffusion model with linear (Langmuir) adsorption. It was concluded that migration of metal ions would occur at a rate proportional to the size of the particles in the cover.

Permeability of materials of various grain sizes can be taken as an indicator of ability to retard leaching (the two will be considered inversely proportional). The coarser the material, the more permeable it is. Permeabilities reported in Lambe and Whitman show clays being classified as generally being "practically impermeable" or having "very low" permeability. Sands are generally classified as of "high" permeability. Silts would vary between these two classifications. Permeability is also dependent on such factors as void ratio and composition. Clays and materials with clay-sized particles such as bentonite find

application as liners in ponds, lagoons, and similar bodies of water as an impermeable layer designed to retar leaching and aid in fluid retention. Similarly, clays would be the best type of inert cover for retarding leaching of spilled chemicals on a waterway bottom, if other factors are also favorable (e.g., scour resistance and ease of emplacement).

In addition to the effect of grain size on permeability and therefore leaching, the ability of a cover material to adsorb certain chemicals and its ion exchange capacity are important considerations in assessing its ability to retard leaching. Adsorptive and ion exchange capacities apply mainly to clays and are very site specific, depending on the aquatic chemistry, the particular clay minerals present in the cover, the grain sizes, and the chemical that is being covered. In general, the ability of clays to physically/chemically tie up certain substances (mainly organics and metals) must be considered an additional advantage in their suitability as a covering agent.

5.3.2.3 Impact on Biota. There are two areas of concern regarding biotic effects: immediate impact of the dump and long-term effects of the bottom cover. It must be anticipated that a hazardous chemical spill that is to be covered will have already created a very impoverished benthic community, and therefore the immediate biotic effects of deploying the cover materials should be negligible. Indeed, any covering layer should be of sufficient thickness to ensure destruction of any surviving benthic organisms in order to preclude reexposure of the spilled chemical through escape holes. Covering depths for this purpose depend on the ability of the indigenous organisms to escape. This will vary from 10 cm for Anodonta, 34 20 cm for Nepthysincisa and Mulinia lateralis, 40 and up to 50 cm for some species of deep burrowing bivalves.

For long-term effects, spill response coordinators should consider the bottom characteristics indigenous to the site. The biota of the area likely to recolonize the covered site will be attracted by material characteristics (especially grain-size distribution) compatible with the natural bottom sediments. In many cases it may be desirable to select an incompatible cover material, one that will discourage recolonization and thereby preclude reexposure of the contaminant by organisms burrowing from the top. If recolonization occurs, depths should be greater than the burrowing ability of the new benthic organisms; this depth will generally be less than the depth through which the same organisms can escape.

Turbidity and suspended solids can also create biotic impacts in the water column during and after a covering operation. Fine-grained materials are generally more likely to cause these problems than coarse-grained materials in the short term. Bentonite, for example, has been known to cause fish kills due to gill-clogging during aquatic applications. After consolidation, however, fine-grained materials will have a lower tendency to be eroded and resuspended, which will lower their impact on biota.

5.3.2.4 Cost and Availability. Information regarding cost and availability is presented here for selected covering agents. Those selected included materials which were considered to be either generally available, available over selected but nonetheless broad regions of the country, or of special concern because of adsorptive or other properties.

Generally speaking, commercially available materials will require lead times of days to weeks, with the largest lead times required for specially processed material, such as special purpose clays. Overland transportation by railroad or truck is available, with trucks being the fastest. (There may be difficulty in arranging for shipment on a short notice, however.) Special purpose materials such as expanding bentonite may be mined in only a few localities, and for limited uses, compounding both cost and availability problems. Naturally occurring (unprocessed) materials of either coarse- or fine-grained size will likely provide the most cost-effective cover and will often be in close proximity to a spill.

A point to remember in reading this section is that the volumes of covering material are generally assumed to be the same whether dry or in-place. That is, 1 cu yd of dry sand, dry clay, or other material will be approximately equivalent to 1 cu yd of the same material when

consolidated in place on the bottom. Computation of required volumes of cover is based on this reasonable assumption. (Clays or other fine-grained materials will be watered down for application, but will consolidate considerably after application.)

Coarse-grained materials, such as sand, gravel, or crushed stone appear to be among the least expensive of the covering agents listed and are generally available throughout the country. Washed and sorted sand, gravel, or crushed stone cost from \$2.75 to \$3.75 per cu yd FOB production plant. (These figures are based on prices in the Boston metropolitan area. Costs throughout the nation are expected to be of similar magnitude.) Overland transportation by truck to a loading dock would be \$0.30 per ton for the first mile and \$0.06 for each ton-mile thereafter. The cost of a ton of material delivered 40 miles, then, would be approximately \$3.25 to \$4.00. To this must be added waterfront handling costs and transportation to the spill area. Rail transportation has also been used for transporting sands and gravels, but rehandling is required.

These materials (specifically the sands and gravels) are also present in continental shelf deposits located along the eastern seaboard in relatively close proximity to major transportation centers, such as New York and Boston. Submerged deposits are known to exist in the Great Lakes. Hopper dredges could pick this material up for direct deposit at the spill site for perhaps \$2.00 to \$3.00 per cu yd, unsorted, the exact cost depending on transportation distances. Sorting for use in specialized applications such as the sand spray booms (to be discussed later) would require additional handling on land, however, and would raise the cost.

Ground glass was investigated as to covering potential. It is available in a variety of grain sizes as fine as 200 mesh. One industry source reported that scrap glass material, the cheapest, is available in limited quantities at a cost of from \$100 to \$270 per ton delivered (about 1/2 cu yd). The material is dirty. In this case, cost does not appear to justify further attention. However, should the material be available in an emergency, it could be used.

A number of <u>fine-grained materials</u> (chiefly clays) with promise as covering agents have been surveyed. Generally speaking, costs of processed clay products such as bentonite, fire clay, ball clay, etc., will exceed naturally found materials by an order of magnitude or more. Availability may also be restricted, as production of such processed products may be limited to a few localities (this particularly applies to bentonite). Lead times may also be significant. While it does not appear that these high-cost special purpose products can be feasibly used for covering large areas, they are listed and discussed in Appendix F in the event that a situation-specific instance might arise such that they will be needed.

Naturally occurring deposits of fine-grained sediments could be obtained by dredge from within harbor and channel areas immediately prior to use for covering. Shelf deposits are also widely available, especially along the east coast. These could be obtained for approximately the cost of dredging and transporting (about \$2.00 to \$3.00 per cu yd, exact cost depending on transport distances from the source to the spill site).

5.3.3 Active Covering Materials

One covering strategy mentioned earlier involves the emplacement of a second chemical compound on the spilled hazardous chemical. This second compound would be chemically "active" (i.e., it would readily react with the spilled compound to neutralize or otherwise decrease its inherent toxicity). However, the active covering strategy differs from the inactive covering strategy because each spilled compound must be dealt with on a case-by-case basis. There are no universal active covering agents.

While active covering agents must be dealt with individually, some general conclusions can be drawn as to the importance of specific inplace properties such as chemical compositions, leaching, etc. In this regard it is useful to draw some general parallels between the active and inert covering agents, followed by discussions specific to a number of obvious covering possibilities applicable to the hazardous materials

under study.

5.3.3.1 Susceptibility to Scour and Erosion. There are some important differences between the active and inactive materials in terms of their in-place properties. First, with respect to susceptibility to scour and resuspension, the purpose of an active cover is to react with the spill, not solely to cover it. It is important only that the active cover remain in place long enough for this reaction to take place. Since most of the active materials are fine grained, many of the considerations (turbidity generation, in-place erodibility) discussed with the clays will be pertinent here. To alleviate the possibility of scour or erosion prior to inactivation of the spilled material, the active covering material could either be used alone or in concert with an inert "stabilizer." In this case the active material could be mixed into an inert base, the inert base acting as an antierosion vehicle. Mixing could occur in a barge, on land, or perhaps through slurry injection into a pipeline discharge. Another option would be to cover the active covering layer with a scour-resistant inert layer.

It should be noted that some active materials (gypsum, limestone) are pozzolanic in nature: that is, they tend to form cements. In this respect, these active covering materials may also be considered as a counter-erosion measure. Mixture with sand or a similar inert material could form a thick cement-like cover over the spill.

- 5.3.3.2 Ability to Retard Leaching. Another major difference between the active and inert covering materials is that the ability to retard leaching is not considered the key to the successful application of an active material. Most of the materials under consideration here are fine grained, and might have some similarities to clays and silts in this regard, though a generalization is hard to draw. Should retardation of leaching become important, a mixture with or subsequent layer of a suitable inert material could likely be used to reduce permeability.
- 5.5.5.3 Chemical Characteristics/Impact on Biota. While the inert covers have little or no chemically related impact on biota, the active covering agents do. Indeed, impacts on biota may result in the

early elimination of some potential covering materials from consideration for some spill scenarios. While accuracy of placement of inert material is important only from the point of view of cost effectiveness, the misplacing of active materials could be harmful to some organisms that had not been in the hazard zone of the spill itself.

5.3.3.4 Selection and Characteristics of Candidate Covering

Materials. The literature cited in this report and the experience of the authors have suggested a number of materials which have been considered for use as active covering agents. These considerations have always been made on a case-by-case basis, i.e., a specific active compound to react with a specific contaminant or spill under a specific set of environmental conditions (e.g., work related to covering of mercury-contaminated sediments). It is not sufficient to provide a fixed list of candidates for active covering materials as has been done with the inactive materials. Each spilled compound must be separately evaluated by a chemist familiar with both the compound and its chemistry and the environmental conditions (salinity, pollutant loads, etc.) at the spill site. Only with these factors fully understood can an informed selection of an active covering material be made.

A typical list of active covering materials, developed through reference to the hazardous material literatur, is presented in Table 5-3. Of the compounds and agents listed in the table, the carbon ased and sulfide-based active agents have probably received the preatest amount of attention in the literature. However, they do not readily lend themselves to the compounds which are considered most amenable to burial in this chapter. (Carbon-based compounds are most effective against organics; sulfide compounds are effective against heavy metal wastes which have insoluble sulfides.)

The generic category of adsorption agents is also not particularly useful as a permanent cover, though they may be useful in temporarily tying up contaminants prior to dredging. Adsorptive materials (such as clays) are known for their cation exchange capacity. As a heavy metal cation is released from a spill, the clay would adsorb it. The problem arises with the reversibility of the adsorption process. Con-

Table 5-3
Active Covering Materials

Material	Active Agent(s) or Mechanism	
Scrap iron	Iron oxide absorption	
Sulfide ores - pyrite	Iron, sulfide	
Clays	Adsorption	
Diatomaceous earth	Adsorption	
Manganese dioxide	Adsorption	
Proteinaceous wastes	Sulfide	
wool chicken feathers xanthates		
Carbon compounds	Adsorption (esp. organics)	
activated carbon lamp black bone char		
charcoal		
Calcium carbonates	Carbonate, acid neutralization	
limestone stucco lime spent tannery lime chalk		
Gypsum (calcium sulfate)	Sulfate	
Sulfur	Sulfur	
Potassium Permanganate	Oxidizing agent	
Alum (aluminum sulfate)	Aluminum, sulfate	
Alumina (aluminum oxide)	Adsorption	
Ferric sulfate	Iron, sulfate	
Commercial ion exchangers	Ion Exchange	

ditions could arise which would lead to the release of the adsorbed metals, making adsorption agents poor burial materials. For example, significant changes in salinity, pH, or dissolved oxygen could reverse the process. Active covers which actually react with the spilled material are not as likely to revert in this manner and hence offer a more permanent solution—one more useful in burial. Similar considerations apply to the carbon compounds, which are most effective on organics. The possibility of using coated materials (e.g., iron filings) for adsorption and quick recovery will be considered in Task IV (Chapter 6).

Commercial ion exchangers are usually petroleum based and therefore quite expensive. They may not be readily available in quantity when needed. Anion exchangers may be overwhelmed by saltwater chlorides and sulfates. Cation exchangers may be overwhelmed by saltwater sodium, calcium, and magnesium. Application to burial is not recommended, though quick recovery techniques are considered under Task IV.

Typical application of a number of the remaining active covering agents plus estimated costs are shown in Table 5-4. The covering agents are cross-referenced to the spilled materials under consideration. All of the active agents are readily available on a fairly uniform basis throughout the country, and all can be purchased in a fine-grained form. The active agents all have major industrial uses which should make them generally available in truckload or rail car quantities. Many of these materials are also available as industrial by-products in selected locations (e.g., gypsum from phosphate ore processing in Florida). For such instances, costs can be drastically cut from quoted levels.

Properties of the high potential candidates for active burial of the hazardous chemicals under study follow. It should again be noted that the list is specific only to those chemicals being considered for burial in this report. Spills of other materials should be handled on a case-by-case basis.

Table 5-4
Selected Active Covering Agents: Cost, Applications,
and Specific Gravity

Active	Spilled	Typical	Specific
Cover	Material	Costs	Gravity
Gypsum	BaCO ₃	\$ 100/ton	2.3
Iron Sulfate	Ca(OH) ₂	90/ton*	3.1
A1um	Ca(OH) ₂	140/ton	1.7
Limestone	PbHAsO ₄	10/ton*	2.7
Sulfur	Phosphorus	120/ton	2.0
Alumina (hydrate)	Alf ₃ , Caf ₂	110/ton*	4.0
Potassium Permanganate	Phosphorus	1650/ton	2.7

^{*} Not including freight, which might run \$20 to \$60 per ton depending on mode and distance.

Gypsum (Calcium sulfate)

For use against barium carbonate to precipitate insoluble barium sulfate.

May degrade biologically to form ${\rm H}_2{\rm S}$, especially in anaerobic conditions.

Should not cause any toxic problems under aerobic conditions.

May actually harden and seal surface through pozzolanic-type cementitious reaction.

Ferric sulfate (Iron sulfate)

For use to slowly neutralize ${\rm Ca(OH)}_2$ (CaO and ${\rm CaC}_2$ which release ${\rm Ca(OH)}_2$).

This compound is weakly acidic. May be slightly toxic to pH-sensitive benthos if it is not properly placed on the spill.

Under aerobic conditions hydrous iron oxides may form and with their adsorption properties will scavenge heavy metals from water. May coat gills of bottom-feeding fish.

Under anaerobic conditions FeS (insoluble) will form.

Alum (Aluminum sulfate)

Same purpose as ferric sulfate (neutralize Ca(OH)2).

This compound also weakly acidic (see ferric sulfate); may degrade biologically to form H2S.

Under aerobic conditions hydrous aluminum oxides may form (similar to hydrous iron oxides).

Limestone (CaCO3 perhaps with MgCO3)

For use to maintain basic conditions in order to keep lead arsenate insoluble.

This compound is weakly basic (caustic).

May be slightly toxic to pH-sensitive benthos if it is not properly placed on spill. Beneficial to organisms with calcareous parts.

May cause pozzolanic reaction as with gypsum.

Sulfur

Could be used to react with phosphorus.

Also considered as a hazardous material when spilled.

Alumina (Aluminum oxide, hydrated form)

For use against aluminum fluoride and calcium fluoride.

This material is used commercially in fluoride removal (esp. drinking water treatment). Adsorbs fluoride while some fluoride reacts to form aluminum fluoride.

Potassium permanganate

Possibly could be used to oxidize phosphorus in place.

Widely used oxidizing agent, especially in drinking water treatment.

Highly reactive when in solution. Could be toxic to benthos and bottom-feeding fish if not placed properly. Toxicity, however, is low relative to the phosphorus it is intended to react with.

Hydrous manganese oxides are a reaction product. Can coat gills of fish and scavenge heavy metals through adsorption.

5.3.4 Chemical Additives

These agents are chemicals which can be added in some manner to a covering material in order to modify bottom chemistry and retard the entrance of spilled materials into the water column. Such additives will not be universally applicable to spills of the materials under study, though preliminary investigation reveals that the effects of spills of barium carbonate and lead arsenate could be lessened through such techniques. Due to the fact that application of these chemicals is not generally through simple burial techniques and also due to the general lack of large-scale field experience associated with their application, these chemicals will be considered further in Chapter 6. At that time, any special application methods and costs, if available, will be discussed. Comments here will be limited to an identification of chemicals of potential value and to results of past experience with them as reported in the literature.

Much of the work pertaining to the use of chemical additives was accomplished under the auspices of the EPA in the late 1960's and early 1970's when efforts were being made to retard the entrance of mercury from bottom sediments into overlying waters. This work has been supplemented by investigations into the control of heavy metal spills in an aquatic environment.

Feick, Johanson, and Yeaple 41 have evaluated various means of immobilizing mercury in contaminated sediments. They found that the mercury binding capacity of sediments may be increased by the addition of sulfur compounds, such as long-chain alkyl thiols, inorganic sulfides, or natural proteins. Long-chain alkyl thiols were found to be most useful, as they were particularly effective in binding mercuric and methylmercuric ions and can readily be applied to bottom sediments by the use of appropriate surface-active agents. Thiols, however, were found to impart objectionable taste and odor to the water. Applicability of thiols to the present case will likely be restricted to spills of barium carbonate and lead arsenate.

Ziegler and Lafornara 42 have stated that the spills of various heavy metal compounds could be treated through the use of sodium sulfide. Active heavy metal ions (such as lead ions) would be removed from solution and precipitated out. The precipitate was found to be harmless. Perhaps, then, sodium sulfide could be used as an effective covering additive to prevent the introduction of heavy metal ions into the water column.

Pilie et al. 3 have developed a master matrix of hazardous chemicals countermeasures which cover each of the materials under study. Included in the matrix are actions to be taken in the event of a water spill. Sodium sulfide solutions were suggested as a countermeasure for aluminum fluoride, barium carbonate, and arsenic compounds. Because of the inherent chemical instability of the sulfides of aluminum, barium, and arsenic in the aquatic environment, it is not believed that this method has significant potential for use in covering, however. Neutralization of spills of calcium hydroxide with a dilute acid (such as iron sulfate or alum) was suggested. Suggestions on the use of "universal gelling agents"

were made, and these are discussed subsequently herein.

It should be noted that chemical additives should be considered as an option regardless of the material spilled and not just those currently under study. Knowledge of a spilled material's chemistry will generally lead to a chemical that could either neutralize or otherwise reduce the hazards associated with its spill.

5.3.5 Sealing Agents

Sealing of the surface of a hazardous material spill is another alternative to inert covering. Such sealing could be done using concrete and grouts, gelling agents, or polymer films. In the case of concrete and grouts, it is possible to conceive of sealing being accomplished either in conjunction with in situ bottom material or as an entirely separate process using material pumped from the surface. Gelling agent use will require some advancement in technology from that available at the present time. Most efforts to date have been conceived with land and/or surface water gel applications. Polymer films have been laboratory tested, but have not undergone full-scale field tests, so their technology remains somewhat underdeveloped.

5.3.5.1 Cement-Forming Mixtures. A Japanese firm 43 has recently done work in dredged material stabilization and deep-mixing of sediments using cement-forming compounds. Inorganics such as portland cement, gypsum, lime, and water-glass have been used to solidify both sludges and in-place sediments. Organic materials such as chemical grouts, asphalts, and resins have been dismissed by the Japanese on the basis of cost. Deep-mixing, using apparatus described in Section 5.4.2.3, has been accomplished with success. Methods using portland cement and lime appear to have particular significance for this project.

TRW⁴⁴ has studied the stabilization of wastes using both inorganic and organic cementation techniques. (Organic cementation techniques require heating and are not considered further for the purposes of this report.) Inorganic cements were classified as those materials which, when mixed with water, will form pastes that will harden in air or under water. Examples given include portland cement, lime, plaster of paris,

and calcium aluminate cements. Inorganic cement-forming mixtures were classified as mixtures, not necessarily cementitious in themselves, that would react with each other to form hardening compounds. Lime-clay, lime-pozzolan, and calcium aluminate-calcium sulfate were suggested. (Pozzolans include such material as diatomaceous earth, fly ash, and pumicites.) The lime-clay mixture suggests an immediate application of hardening agents in muddy harbor bottoms and, in fact, has been represented in the Japanese method outlined above.

In addition to the above techniques, grouting is often used in the offshore oil industry to secure the legs of a structure in oversized holes in hard bottom areas. 45 In these methods, grout is generally injected into the bottom through pipes from the surface. The grout is pumped into an area that has generally either been filled with drilling mud or filled with mud then flushed with seawater. Several variations on this method are used and they will be investigated in Task IV as to possible usefulness in immobilizing spilled hazardous materials.

5.3.5.2 Gelling Agents. A number of potential gelling agents have been included in the literature on hazardous material control. However, applications are generally intended for either land or surface water spills.

Pilie et al. have reported on the use of a "universal gelling agent" consisting of four active polymer ingredients (including Dupont Gelgard for use in aqueous solutions) and one inert powder. This agent is considered particularly useful in the congealing of land spills and surface water spills of liquids. Spills on water would be contained by booms and cleaned up mechanically. The agent has applicability to a broad range of chemicals. Among these is phosphorus and it has been suggested that a trapped mass of the material be injected with the gelling agent to aid in containment.

Michalovic et al. 46 optimized the composition of the universal gelling agent against application ease, gelling speed, and cost. A number of commercially available substitutes were also tested. Again, work was directed towards spills of liquids. A formulation of polyacrylamide, a polytertiary butylstyrene, a polyacrylonitrile rubber, a

polycarboxymethyl cellulose, and a fused silica was the optimum mix. However, spilled chemicals considered in that study did not include any of the 70 chemicals presently under study. A xanthate gum-polysaccharide (tradename Kelzan) was found to form a gel in the presence of water and may have applicability to this project. It met evaluation requirements of dry powder, formation of gels without extreme stirring or heating, and good gelling efficiency. Bottom application methods were not evaluated. Most of the gelling agents discussed in the literature were less dense than water, and therefore, new formulations would be needed to deal with hazardous chemicals that sink.

The EPA, in a brochure describing the control of oil spills and other hazardous materials, has mentioned a number of gelling agents to be surface-applied to oil spills on water. Possible gelling agents listed included molten wax or soap solution, lanolin, liquid solutions of natural fatty acids, soaps of alkaline metals, treated colloidal silicas, the amine isocyanates, and polymer systems. Application and distribution problems, costs, and pickup methods were listed as problem areas. Application to the present case appears tenuous, because these materials tend to float.

5.3.5.3 Polymer Films. Polymer film systems have been the subject of a report by Widman and Epstein. 47 Three types of film systems have been suggested: coagulable polymers (alcohol soluble nylon), hot melt materials, and commercially available films. Systems for the application of these materials are discussed in Section 5.4.2.3.

A number of different film materials have been tested. It was noted by Widman and Epstein 47 that preformed nylon 6 (polycaprolactum) was most effective when used to retard both inorganic and organic mercury. Other films (high-density polyethylene, low-density polyethylene, polyvinyl chloride (PVC), alcohol-soluble nylon, and polyethylene-vinyl acetate) were effective against inorganic forms of mercury only.

From an equipment and cost standpoint, the use of preformed polymer films (either nylon 6 or higher density PVC) appears to be the best option. Further consideration of polymer films is given in Chapter 6.

5.4 EMPLACEMENT AND EROSION CONTROL MEASURES

5.4.1 General

Several methods for the emplacement of covering materials have been investigated. Initial attention was paid to existing methods of dredged material placement: point dumping from scows, barges, and hopper dredges and open-pipe discharges from hydraulic dredges. These methods, readily available and capable of placing a cover, were found to have a number of drawbacks requiring further attention (uneven cover, turbulent impact on bottom and scouring). Several alternatives to these techniques, such as hopper dredge pump-down or sand-spray systems, hydraulic dredge pump-down, and submerged discharge apparatus for hydraulic dredges, have potential for emplacement, although at an increase in cost for new equipment. Further attention was given to special-process apparatus (film roller systems, deep chemical mixing apparatus) as well as low-potential techniques such as plowing and the use of grab-buckets for emplacement. Results of research into all of these options are reported in this section.

Silt curtains, borrow pits, and submerged dikes have been mentioned in the literature as possible turbidity or dispersion control methods for dredging operations and could be used in conjunction with the covering methods outlined above. Control of the covering material during emplacement is a concern from two points of view. First, the covering material may tend to disperse during emplacement. This concern would especially apply to fine-grained materials, which may form a mudflow capable of travelling great distances under water. This kind of dispersion must be avoided to minimize loss of covering material.

Second, turbidity caused by the covering action would have a negative effect on biota in the area. Thus, dispersion should be controlled for both economic and environmental reasons.

Erosion control methods, such as artificial seaweeds, submerged dikes, and artificial breakwaters, may be necessary in high current areas. Scour velocities will vary with the covering material. Cases of erosion of the covering layer could occur, reexposing the spilled

hazardous material. Erosion control measures could reduce these effects. The possibility also exists of downstream or down-current trenches being excavated to catch any cover and hazardous material that might erode away. These methods are beyond the scope of this section on burial techniques, however.

5.4.2 Emplacement Methods

5.4.2.1 Hopper Dredges. Hopper dredges will be most useful in unprotected waters or deeper harbor and channel areas where sea conditions might be severe enough to restrict the use of barge-mounted equipment. Fully loaded hopper dredges operated in the U. S. by the Corps of Engineers draw from about 13 to 31 ft of water and have hopper capacities ranging from 720 to about 8000 cu yd. Table 4-3 provides a listing of Corps hopper dredges, their characteristics, and base District.

The usefulness of hopper dredges for in situ covering is restricted by both availability and draft. There are only two Corps hopper dredges on the west coast, for example, and they may be very distant from a spill, should one occur. Further, even the smallest hopper dredges draw 13 ft of water and are restricted from general use in waters of lesser depths. Draft restrictions may also be imposed by the mode of use of the hopper dredge. For example, point dumping cannot be done in less than 20 ft of water, due to additional depth required for safe operation of the bottom doors which would release the covering material. Availability of covering material is generally not expected to be a problem with conventional hopper dredge application, as the dredge can seek a "site-of-opportunity" for pick up from among nearby harbor channel areas, ocean bottom, or similar locations. The need for special materials would remove this advantage.

Point Dumping. Point dumping to cover a spill would be a straight forward application of traditional hopper dredge operations to the
covering problem. The dredge could possibly even use material from
nearby channels as cover. One important problem associated with this
technique would be precision navigation in the vicinity of the spill (to
be discussed later). Further, draft limitations outlined earlier would

preclude use in shallower waters. Seven to eight feet of water beyond the loaded draft is required for point dumping. There is no physical maximum depth at which dumping may be accomplished, though tank tests 48 and mathematical models 49 reveal that, for like volumes of similar material, dispersion increases with depth of water. Ability to achieve precision placement of the cover therefore decreases with increasing depths. At some point, the depth of water will make point dumping infeasible.

Completeness of bottom cover will be of concern should point dumping by hopper dredge be used, as will the impact of deposited material on the bottom. A complete understanding of these phenomena does not currently exist, as few efforts have been made to monitor the discharge of a bottom-dumping hopper dredge, and only limited tank tests have been accomplished. Further, most of the efforts have been for projects involving silts and clays, which behave differently from coarser grained, less cohesive materials such as sand.

Test tank evaluations of bottom dumping of silts and clays have been accomplished by JBF Scientific Corporation. 48 It was found that dump size, depth of dump, and percent moisture of the dumped material had the most significant impact on nature of deposition. The method of discharge (barge or hopper) and type of water (fresh or salt) were found to have little or no influence on dump characteristics evaluated during the study.

Observations of simulated dumps showed that low moisture content silt and clay materials would tend to mound on the bottom, the dump being characterized by a very rapid descent phase, little cloud growth, and little spreading of the material on impact. High moisture content materials were characterized by a slow descent phase, cloud expansion due to entrainment, and a rapid flow of material across the bottom after impact. Little or no mounding was evident.

A hopper dredge investigated during operations in San Francisco Bay 48 was found to have two layers of material in its hopper: one a low moisture content material on the bottom of the hopper, the other a relatively high moisture content material on top. Distribution of

the two layers will vary with the amount of overflow allowed from the hoppers during the dredging cycle: the more overflow allowed, the higher the level of low moisture content material.

Tank observations of a simulated two-layer hopper discharge have been made. They indicate that the simultaneous dumping of the two layers results in characteristics that are basically the same as if each of the layers was dumped separately; that is, the low moisture content material (100 percent moisture was used) tended to mound on the bottom, while the high moisture content material (400 percent moisture in the experiment) descended more slowly and tended to spread upon bottom impact. Flow behind the 100 percent moisture material (i.e., the "wake" of the first material to descend) was noted to slightly affect the 400 percent moisture dump characteristics.

Impact velocities on the bottom vary with percent moisture of the dumped material. The low moisture material will impact at its equilibrium velocity. Descent energy is generally dissipated during this impact with little being contributed to spreading. The high moisture content material will decelerate upon descent, forming a cloud. It impacts the bottom more slowly than the low moisture case and much of the energy of descent is dissipated in horizontal movement along the bottom, reducing the likelihood of turbidity and scour.

Sand lacks the cohesiveness of low moisture silts and clays and therefore may be expected to mound to a less significant degree. The only comprehensive study of sand dumping from a hopper dredge is that of Sustar and Ecker, who used a variety of techniques, including divers, at an operation offshore from the entrance to San Francisco Bay. They found that, on bottom contact, sand surged radially outward so rapidly that the maximum bottom deposition was only 2 in. Scouring of the bottom was noted in some areas. Although this result cannot be extrapolated to the present discussion quantitatively, in a qualitative sense it indicates that a series of dumps could provide a thin layer of cover on top of any spilled material. The observed process of scouring, however, may indicate a tendency to resuspend any spilled hazardous material, a process which could render point dumping ineffective.

In summary, it appears that point dumping from a hopper dredge is an attractive option in deep harbor and open ocean areas from the point of view of ease of performance. Techniques are time-tested. Further, material from nearby channels or other areas could be used for cover. Problems in the availability of such dredges will occur due to their low numbers. Other problems may arise from the impact of the dumped material on the bottom (particularly with low moisture silt and clay) or from scour in the event that sand is used. Both of these may tend to resuspend spilled hazardous materials, rendering the point dumping process ineffective. Lack of control over the material's final location and unevenness of cover also could reduce effectiveness of this method.

Pump-Down. One means of avoiding the potential scouring, turbulence, and mounding processes associated with point dumping would be to design a system, referred to here as pump-down, so that the dragarm of the hopper dredge could be used to discharge covering material only a few feet above the bottom. This system, originally proposed by Johanson, Bowen, and Henry, 49 would apply to hopper dredges already having pump-out capability and would require the installation of additional piping on the dredge. Sand or other covering material could then be pumped out of the hoppers, down the dragarm, and deposited within a few feet of the bottom. By properly choosing a forward speed of the dredge, the material would effectively settle like a blanket, reducing turbulence on the bottom.

The plumbing for a hopper dredge pump system with pump-out capability generally incorporates dual pumps whose suctions are connected to the two dragarms and the collection system. The discharge sides of the pumps connect to the hopper distribution system and the overboard discharge ports. The schematic for allowing the proposed pump-down discharge is shown in Figure 5-1. The proposed flow path, shown by arrows, is from the hoppers into the collection lines to the inlet of each pump. From the discharge side of the pumps, the flow must be routed to each dragarm port. This piping must be added to implement the concept and is shown by dashed lines in the schematic. The modification involves cutting into the main discharge lines at "D" at Y-branches

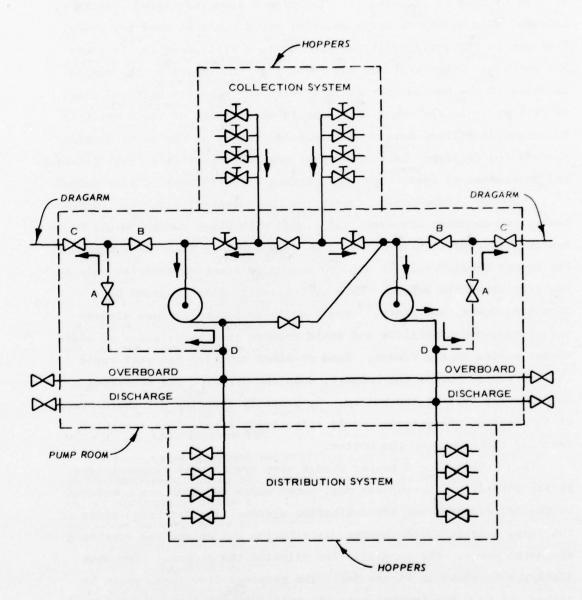


FIGURE 5-1. HOPPER DREDGE PIPING SCHEMATIC.

and running full-size discharge pipe, with valves "A" installed, over to the dragarm ports. Y-branches must be added just inboard of the dragarm valves "C" between valves "C" and "B," and valve "B" must be connected into the system.

The preliminary cost estimate outlined below (accomplished in 1975) includes engineering and design labor, installation labor, and material costs and assumes that the installation would be performed during regular shipyard overhaul in order to avoid loss of operating time.

Engineering Design	\$ 25,000	
Materials	100,000	
Installation	25,000	
	\$150,000	

The pump-down operation is the same as that for pump-out except that the dragarms are lowered before the dredge pumps are turned on, and the appropriate valves are set so the discharge flow is delivered to the drag ports. With due regard for the bottom contour, the drag operator sets the draghead as close as he safely can to the bottom, preferably to within a few feet. The dredge pumps are then turned on and cover material flows down the dragarm and is discharged through the draghead.

Draft limitation would depend on the dredge. Referring to Table 4-3, seven hopper dredges with direct pump-out capability are noted. Loaded drafts are from about 13 to 30 ft. Add several feet to this for minimum drafts for safe navigation. Maximum dredging depth, and therefore, maximum effective depth at which the direct pump-down option could be pursued, varies from 36 to 60 ft. It would be possible to use this method in deeper water, though much of its effectiveness would be lost. Bottom roughness would be a factor in the feasibility of this method, as an unusually rough or uneven bottom would require a large distance between the dragarm and the bottom. This would increase turbulence and spreading of the material along the bottom, thus decreasing the ability to place the material accurately.

Another problem with regard to this method is navigation. The draghead of the dredge GOETHALS, for example, is only 10 ft wide, and

precise navigation is only marginally feasible should full, or nearly full, cover be required, even in nearshore locations. Highly precise navigation systems, such as those used for predredging surveys, could be used. Though some improvement could be expected, perfect coverage would still be difficult to obtain.

Spray Boom System. A spray boom system could be installed that would deploy the cover material by spraying it on the surface of the water and letting it sink rapidly to the bottom where it would build up a cover layer on top of the spilled hazardous material. The covering operation would be carried out using a hopper dredge with direct pump out, equipped with two spray booms (port and starboard) and the craning facilities required to handle them. This system would be subject to the same minimum draft requirements as the pump-down configuration. Maximum depths of water for effective use of this method would depend on current and wave condition at the time of application.

The cover material can be stored in the hoppers and, using the main dredge pumps, can be pumped out through the collection system to the spray booms. It would be slurried by jetting water in the hoppers and by mixing water at the pump inlet. The percent solids of the sprayed material would be about 10 to 20 percent by weight. Each boom would lay down an even spray over a width of about 85 ft so that with both booms operating, two 85-ft-wide swaths would be laid down with a separation distance of approximately 85 ft. The configuration is shown in Figure 5-2.

The spray method for applying the cover requires that the material settles to the bottom before it can be transported away from the dump point. If the average water depth were 50 ft, the settling time would be 10 min for fine sand and approximately 1 min for coarse sand or fine gravel. The hopper dredge is particularly well suited for sand and gravel operations because by dredging beyond overflow it can consolidate and compact the load and thereby maximize the capacity of the vessel.

The hardware system required to implement the spray method was described by Tobias 51 for the dredge GOETHALS in connection with a

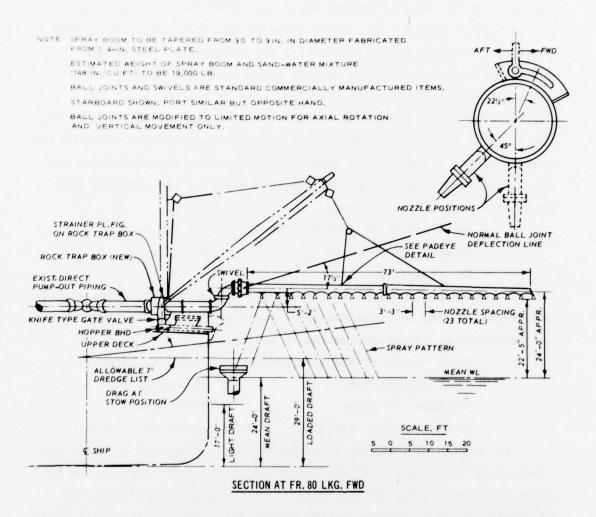


FIGURE 5-2. PROPOSED SPRAY BAR ARRANGEMENT.

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feasibility study of its use as a sand-spreading vessel. Tobias' goal was to sink oil slicks, but the sand spreading method needs no change for application to burial of a spill. Using the cost figures compiled by Tobias as a reference, it is estimated that the spray boom modifications for the dredge GOETHALS would cost \$200,000 at 1975 prices.

A typical example of a spray covering operation illustrates the practical considerations that control the situation. The dredge GOETHALS is to cover an area that is 1 nautical mile long by 1/2 nautical mile wide with a 6-in.-thick cover of coarse sand. The GOETHALS can store an average of 4000 cu yd of mix per load. The sand source is 10 miles away and the sand must be dredged. The GOETHALS can operate around the clock six days a week, the seventh day being a lay day. For these assumptions the number of dredging and covering trip cycles are computed as follows:

Total volume of sand transported = 342,000 cu yd
Capacity of GOETHALS = 4,000 cu yd
No. of cycles = 86

The GOETHALS lays down the cover at 2 knots, while running at full pump capacity with an effective spray width of 170 ft. The sand mixture is controlled at 20 percent solids by volume.

Total volume of mixture pumped = 20,000 cu yd/cycle

Total pumping time = 33.3 min/cycle

Thickness of cover = 0.63 in./pass

Total distance travelled = 1.1 nautical mile/cycle

The pattern of covering is alternated by laying down a single-pass cover along the 1-nautical-mile length of the area followed by the next cover thickness along the 1/2-nautical-mile width. This procedure eliminates holes or troughs in the cover. According to the total distance traveled while dumping, the dredge dumps its load in a single pass along the 1-nautical-mile direction and in two passes when running parallel to the 1/2-nautical-mile width direction.

The cycle time for the dredge breaks down as follows:

Loading sand 2 hr Trip to borrow pit 1 hr
 Cover
 1 hr

 Return trip
 1 hr

 Cycle Time
 5 hr

Navigation while laying down the cover can be provided with several buoys in the spill site plus a precision system such as Raydist. Loran C would be marginal, even in the repeatability mode; that is, using the readings to return to the same spot and then moving over the required distance each time. Thus, the cost of setting up a precision navigation system must be added to the cost of covering, unless the system were already established to be used during filling. It should be pointed out that the navigation requirements for covering are stringent and may require a more sophisticated system than Raydist to minimize the redundant runs necessary to obtain a satisfactory cover.

Costs for covering can be estimated as follows, for the case described above. Based on a 5-hr cycle time and 86 cycles, the total operating time is 430 hr or 3 calendar weeks to lay a 6-in. cover on a 1/2-square-nautical-mile (424 acres) spill site. The operational cost of the dredge based on a daily rate of \$15,000 for 21 operational days and 6 days for mobilization and demobilization of the spray boom system comes to 27 days or \$405,000. This amounts to \$1.18/cu yd of cover, for a 6-in.-thick cover, or \$950/acre. Since there undoubtedly will be holes in the cover, regardless of the navigation system used, approximately 50 percent should be added to this number to allow for redundant runs, bringing the cost for dredge operation alone to about \$1425/acre. The cost of modifying a dredge has been estimated to be \$200,000. Finally, the cost for renting a precision navigation system must also be added.

It should be stressed that these costs are for covering a relatively large area. Smaller areas would be somewhat more expensive to cover (on a per-unit basis) because the time spent maneuvering and getting into position for multiple short runs would increase the total dredge time required per acre of cover.

The relatively long period of time it would take to cover the spill, and the mobilization necessary to convert the dredge to the sand-

spray configuration, decrease the value of this method for emergency covering operations. Many of the hazardous materials being considered require quick response.

5.4.2.2 Hydraulic Dredge/Barge-Scow. A number of emplacement methods are possible using hydraulic dredges, barges, scows, and combinations of these. Open-ended discharge from a hydraulic dredge, point-dumping from scows (possibly loaded by hydraulic dredge), pump-down from loaded scows, and submerged pipeline discharge of dredged or other covering material are all possibilities.

The use of any of these methods offers an inherent advantage over hopper dredge systems in that they are not severely restricted by draft. Depending on size, hydraulic dredges can operate in water as shallow as 2 to 3 ft, making them useful in all but the shallowest of locations. Portable hydraulic dredges are presently marketed in the U. S., making deployment to a spill site possible, though a 2- to 6-day period for mobilization will probably be required. Barges and scows, in particular, could be loaded with specially treated materials and then transported to the spill site for use in covering.

The above methods will be most useful in confined areas. Hydraulic dredges will find somewhat more limited utility in open-ocean areas than hopper dredges due to their poor seakeeping characteristics and the susceptibility of the pipelines to damage by wave action. Seas as little as 3 ft, for example, can render a hydraulic dredge, or barge-mounted submerged discharge or pump-down apparatus, temporarily ineffective. Barges or scows which are generally powered by tugboats and used for point dumping will, depending on their size, find sea conditions somewhat less restrictive. They are quite stable for their size due to the dimensions of their rectangular waterplane.

Open-Pipe Discharge. Open-pipe discharge is commonly used in conjunction with hydraulic dredges and would require no new hardware to be used for covering. This method would be primarily used in relatively protected waters and would most likely consist of the direct use of dredged material for burial.

In the open-p a discharge configuration, a floating discharge line

supported by pontoons is attached to the discharge connection of a hydraulic dredge. Dredged material is pumped through the line and flows out the open end of the final pipeline section, or through a discharge barge (Figure 5.3) connected at this point. This arrangement is especially useful in that it permits covering in relatively shallow water while allowing the dredge to operate some distance away, in deeper water or perhaps in a channel. Maximum pipeline distances (without booster station) can vary from as little as 2500 ft for a 12-in. dredge to 20,000 ft for a 30-in. dredge. Minimum working depths of hydraulic dredges range from about 3 ft for the small 6-in. models to 12 ft or more for dredges in excess of 28 in. Maximum digging depths normally range to about 60 ft unless a submerged pump is used, in which case depths in excess of 100 ft can be achieved. Limiting sea conditions for operation of a hydraulic dredge-pipeline configuration can vary with such factors as size of the dredge and wave period. Swell-compensated cutterhead dredges may also be available, with claims of operability in 6-ft seas.

Covering characteristics of open-ended discharge will vary with the dredged material. Coarse-grained materials, such as sand, will behave as discrete particles during settling following open-pipe discharge. Silts and clays exhibit cohesiveness and will behave differently, often forming a distinct bottom flow pattern (mudflow) and a turbidity plume in the water column, both of which are affected by the cohesiveness of the material.

Schroeder and Pyles⁵² have reported on dispersion patterns of sandy dredged material following discharge from an open-ended pipe oriented parallel to a river current. They found that the material discharged from a pipe will tend to sort itself hydraulically, due to different settling velocities of the particles. Progressively finer particles will be carried farther from the discharge point. Specific discharge characteristics will depend on the nature of the sediment, strength of the discharge flow, and ambient current conditions. No evidence of subsurface sediment flow was noted. Thus, the discharge end of the pipe would have to be moved over the spill site to effect covering.

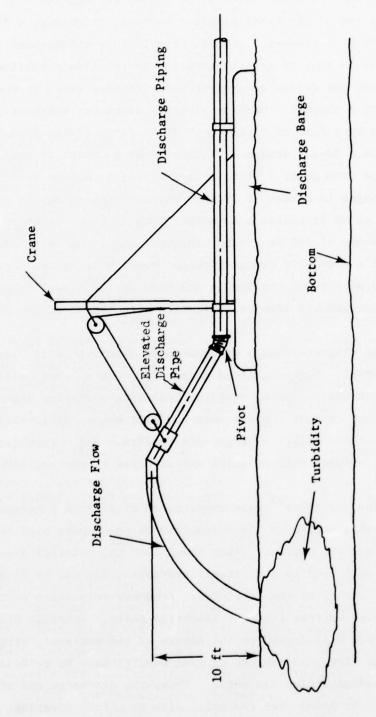


FIGURE 5-3. OPEN-PIPE DISCHARGE BARGE.

Fine-grained, cohesive sediments discharged by a hydraulic pipeline dredge often have associated with them the phenomenon of "mudflow." The mudflow is formed on the bottom in the immediate area of the discharge pipe and can flow radially outwards to distances of several thousand feet. These mudflows have been observed covering the bottom with a layer of anoxic material as much as 2 ft thick. Observations of mudflows reveal them to be capable of flowing in and out of depressions, flowing uphill, and even flowing against the current.

Laboratory work by White ⁵³ indicates that gravity is the prime driving force behind mudflows, with currents having a noticeable, but weaker, effect. Strong currents (speeds unspecified) may prohibit the formation of density currents by turbulent mixing and sweeping the sediment away before it can build up to sufficient concentration for layer development. Observations of mudflows ⁵³ revealed that they move from the discharge point in a layer of constant thickness preceded by a head wave fed from within the flow. There is no evidence of significant entrainment of underlying bottom material.

Mudflows may have usefulness in covering of spilled hazardous material if properly controlled. Since the flow can extend uncontrolled over distances of several thousand feet, confinement appears to be a possible option. Observations by White, ⁵³ Masch and Espey, ⁵⁴ and May ⁵⁵ reveal that:

- o A trench may be effective in stopping a mudflow.
- o A submerged dike may or may not stop or disperse a mudflow, depending on the specific geometry and hydrodynamics of a given situation.
- o Turbulence from a variety of sources can inhibit the formation and progress of a mudflow.

Mechanical devices such as labyrinths have also been suggested for flow control and arise from the third observation listed above. Of all of these, dikes appear to have the best chance of succeeding in the covering situations, since they would confine the mudflow within the specific spill area while also serving to mitigate the effects of outside currents and other sources of turbulence on the spill. In summary, burial using open-pipe discharge is possible. Coarse-grained material such as sand will require frequent moving of the pipe to ensure even coverage, as the material tends to mound. Finer grained, more cohesive sediments will, given the proper conditions, form a mudflow which can travel along the bottom over great distances resulting in a uniform covering. Movement of the discharge pipe is still desirable in order to achieve even coverage over large distances. Covering will best occur in protected areas and could occur over both rocky and smooth bottoms. Depths will be limited by tendency of the covering material to disperse after discharge.

Submerged Discharge. Submerged discharge techniques, using either a simple pipe beneath the water surface or a specially designed barge-mounted diffuser system offer a quantum improvement over above-water, open-pipe discharge techniques. Improvement comes from the increased control available over placement, including reduced turbidity and more predictable bottom flow characteristics of the discharge.

By varying the height of the discharge above the bottom as well as discharge velocity, impact velocity on the bottom can be reduced to levels that will greatly reduce the possibility of scour and resuspension. The use of a diffuser device (Figures 5-4 and 5-5) will further enhance control of the discharge. The diffuser section operates on the principle of radial divergence of flow to slow discharge velocity to acceptable levels. Diffuser systems similar to this are well tested and present few technological roadblocks to development for use in submerged discharge applications.

Submerged discharge techniques would, like the open-pipe discharge system, best be used in conjunction with the existing hydraulic barge/pipeline systems. It is also possible that a pump-down barge being fed by scows could also be used. In either case, a barge-mounted submerged discharge system would be attached to the discharge pipe. Some of the characteristics of such a barge are shown in Figure 5-4. The diffuser discharge (Figure 5-5) would be raised or lowered to the desired level by a derrick on the barge. Also, the discharge would have to be carefully monitored to ensure that no inadvertent creation of shoals occurred.

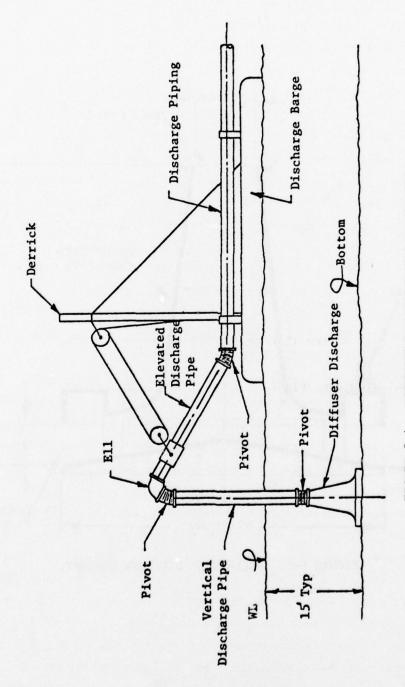


FIGURE 5-4. DIFFUSER DISCHARGE BARGE CONCEPT.

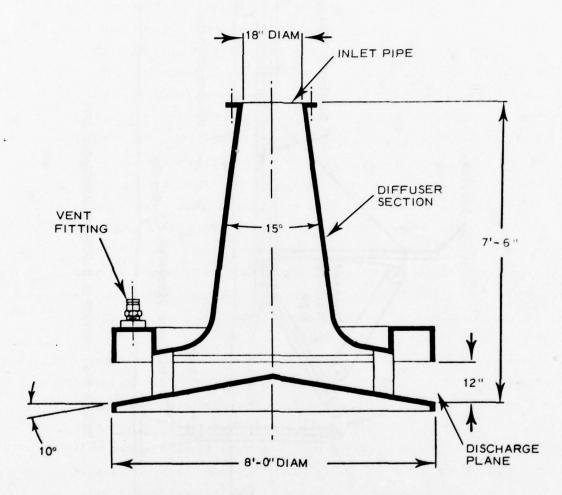


FIGURE 5-5. FULL-SCALE DIFFUSER CONCEPT.

Open-water operation would generally be confined to depths of 100 ft or less, depending on environmental conditions. Difficulty in lowering and controlling the diffuser device would be limiting factors.

Sediment flow characteristics after leaving the diffuser discharge will vary with the type of sediment and current, as well as pipe size, slurry flow rate, and height of diffuser above bottom. Finer grain sizes (predominantly silts and clays) plus favorable current conditions will, for example, aid in the creation of the mudflows mentioned earlier. Sand discharges have not been monitored. However, phenomena similar to the mudflow are not expected to occur and chances of "mounding" and the creation of shoal areas will be increased. In both cases, however, the use of the diffuser device is expected to increase control over emplacement of the material in a spill area, as well as reduce turbidity and scouring due to placement in the vicinity of the spill site.

Complete cover of the spill area can be ensured by repositioning the discharge barge throughout the area as necessary. This can be accomplished by traditional methods (workboats and mooring tackle). It is expected that the need for repositioning will be greater when sand is being used as a covering material due to its tendency to mound. Fine-grained materials will require careful monitoring and control to ensure that their spread is limited.

In summary, the use of a submerged discharge device for bottom covering is an attractive option. Advantages of the system include increased control over location of covering, decreased scouring of the bottom area, and less turbidity in the area. Operations in depths to approximately 100 ft appear possible. Technology for the system exists, though the hardware for a completely barge-mounted system is not currently available. The system would be used in conjunction with existing hydraulic dredges and would be subject to the same environmental limitations. Thus, use in open-ocean waters would be limited by waves and similar factors.

<u>Point-Dump Methods (Barge and Scow)</u>. Hydraulic dredges may be used in conjunction with barges and scows. In such a system the dredged material is pumped into the barge or scow which in turn is pushed or

towed by tug to a dump site. At the site, the material is bottom-dumped. The ready availability of this technology makes it immediately attractive for covering of spilled hazardous materials, and specialized or treated covering material could readily be loaded at a shoreside facility if necessary.

Barges and scows come in two general configurations. One is the "clamshell" type of barge in which dumping is accomplished by opening the entire hull in clam-like fashion. The other configuration consists of scows that are divided into separate bays, each with its own bottom-opening door similar to those on hopper dredges. Sizes of the scows and barges range from 200 to 4000 cu yd capacity, and drafts vary from 7 to 20 ft. Draft requirements will thus restrict this method to use in waters at least 10 to 12 ft deep, the exact depth depending on barge size, door configuration, wave condition, and so on.

The behavior of the material, once it is dumped, is essentially the same as for hopper dredge bottom dumping (discussed previously). Completeness of bottom cover (placing high priority on accuracy of navigation systems) as well as impact of dumped material on the bottom will again be of concern. The low moisture, fine-grained silts and clays, which tend to fall as a unified clump, will impact the bottom at significant velocity causing resuspension of bottom sediment. The higher moisture and/or less cohesive material (e.g., sand) will experience an outward radial surge upon impact, perhaps causing less turbulence in the area of the spill. Scouring was noted during field tests of bottom-dumped sand, however.

In summary, point dumping by barge and scow is operationally attractive. Problems may arise, however, in the accuracy and completeness of cover as well as from the impact of the dumped material on the bottom, which may cause scouring and sediment resuspension.

Pump-Down Methods. The potential limitation on bottom-dumping from scows or barges caused by sediment resuspension can be overcome through the use of an unloading barge that pumps the material out of the scow and down a discharge pipe, whose termination is set close to the bottom, similar to the submerged discharge setup discussed previously. Such

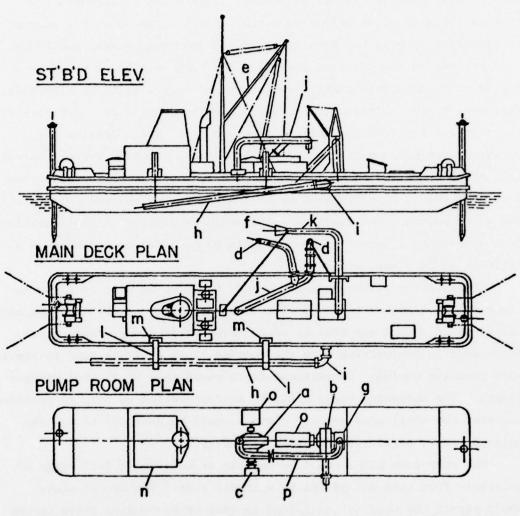
vessels are used in Europe for pumping dredged material ashore, but are not yet available in the United States. Figure 5-6 illustrates the typical features of an unloading barge. Application of such a concept to precision dumping has been described by Johanson, Bowen, and Henry.

For use in the covering exercise, the pump-down barge would be moored or spudded into place, with scows and barges tying up alongside. Equipment on the unloading barge would then be swung over the hopper of the scow and the load hydraulically pumped out. The unloading barge would be configured much the same as a hydraulic suction dredge, except that the suction system would be designed to pump out barges and scows down a discharge pipe designed to be lowered to any desired point within the water column. The discharge pipe would be similar in configuration to a dragarm on a hopper dredge or could be modified to accommodate a diffuser as in Figure 5-5.

Installation of the pump-out barge at the spill site could be implemented in a number of ways. The vessel could be secured on four mooring lines in such a way that it could move itself along a dump track. Spuds used in conjunction with the mooring lines could be used to provide more positive motion. Operational depth would then be limited by spud length. The unloading barge could be self-propelled to help in positioning over the spill area and its engines could be designed to tow the adjacent scow, permitting underway discharge.

The pump-down barge would be capable of handling a full range of material—from sand and gravel to silt and clay. The use of scows would permit the material contained in them to be treated prior to use for covering, if necessary. It is not necessary that they be filled with dredged material. A setup can be envisioned where covering material, treated as necessary, could be made available at a shoreside location and then transported to the spill site.

It is anticipated that silts and clays handled in the above manner and discharged beneath the water would exhibit the characteristics of the mudflow discussed previously. Since the layer of fluidized mud discharged in this manner could spread several thousand feet, it might be necessary to provide submerged barriers to prevent the flow from



- a. jet spray pump
- b. dredge pump
- c. sea chest
- d. spray nozzles
- e. cranes
- f. suction head
- g. stone chest
- h. pump-down arm

- i. pump-down elbow, pivoting hull
- j. jet water lines
- k. suction pipe
- 1. pump-down davits
- m. pump-down winches
- n. diesel power plant
- o. hydraulic motors
- p. priming pipe

FIGURE 5-6. PROPOSED PUMP-DOWN BARGE.

getting out of control. Sand and gravel, or other coarse material, would probably not flow in such a manner, and it would be possible to lay down bands of the material with low energy impact on the bottom. Precise positioning and movement of the unloading barge would then be necessary to secure an effective cover. Cover could be achieved using a two-pass system with one series of passes lengthwise over the area to be covered and the other set of passes in a widthwise manner. As with the case of hopper dredge pump-down, bottom roughness and precise navigation could pose problems.

Johanson, Bowen, and Henry, ⁴⁹ while studying the potential impacts of similar pump-down techniques using hopper dredges, noted that it was possible to create active eddying and multidirectional diffusion if pumping occurred at too high a rate. This could cause resuspension of bottom materials, or, possibly, prevent the formation of mudflow which in this case could be of beneficial use. Reduction in speed of the pumps or repositioning of the discharge arm could help alleviate these problems.

The estimated cost of a pump-down barge 150 ft long by 30 ft wide is \$3.5 million (1975 prices) based on the cost of similar equipment. The economic burden of a new vessel can be lessened by modifying available used equipment. A hydraulic suction dredge is particularly useful in this sense, since it comes equipped with a dredge pump system, crane facilities, and mooring equipment. Only the equipment for scow unloading would have to be added.

In summary, the use of a pump-down apparatus to unload scows and barges could provide a major improvement over bottom-dumping techniques by allowing controlled discharge near the point of application. Reduced turbidity, reduced sediment suspension, and precise placement of material could be achieved using these methods.

5.4.2.3 Other Emplacement Methods. Mechanical dredges under consideration in this section are of two types: the clamshell dredge, consisting of a barge-mounted derrick and bucket, and the dipper dredge, similar in concept to the land-based power shovel. The clamshell is traditionally used in softer sediment while the dipper finds application

in harder materials. The dipper dredge can be eliminated from further consideration due to the difficulty it would have in removing covering material from alongside a scow.

It is possible to conceive of a clamshell dredge/scow combination being used as a covering system. One significant advantage of such a system is its ready availability. The clamshell dredge itself would be moved over the spill area by "walking" on spuds, with motion provided by reeling in line attached to anchors. Initial positioning would be accomplished using tugs. Through the use of such locational aids as lasers and channel marks, accurate positioning can be obtained (see Section 5.4.5 for information on navigational aids).

Operation of the clamshell dredge for covering would be in conjunction with barges or scows moored alongside. The clamshell would essentially operate in reverse, retrieving covering material from the barge, lowering it into the water, and depositing it near the bottom to ensure low-energy impact. Material in the barge could be obtained either from a marine or land-based source and could be pretreated as necessary. It is anticipated that such covering would cause relatively little turbulence or resuspension of bottom sediments, although loss of cover material to the water column during lowering would occur, unless an enclosed bucket (see Section 4.2) is used. Documented field experience with this sort of operation is totally lacking.

A number of drawbacks to covering with a clamshell dredge exist, however. Completeness of covering will be difficult to achieve due to the discrete nature of the dumps. Also, the process will be slow due to the nature of the equipment. Further, operation using this type of equipment will probably be confined to protected riverine and harbor areas and waters less than approximately 100 to 125 ft deep.

In summary, clamshell dredges will provide a ready and feasible covering alternative, primarily in protected river and harbor areas. In conjunction with barges or scows, covering material may be placed by a series of discrete dumps using the clamshell operating in reverse. Problems of slowness and completeness of covering will exist.

Barge-mounted roller apparatus systems for either hot or cold

application of polymer film overlays over mercury contaminated bottom sediments have been suggested by Widman and Epstein. 47 These techniques, proposed but never field-tested, will be dealt with in Chapter 6. However, an overview of the suggested technology will be provided here for reference. Specific covering materials will not be discussed in this section, only the hardware.

Three systems were considered by Widman and Epstein. ⁴⁷ These included systems for laying down coagulable polymers (alcohol-soluble nylon); hot melt materials; and preformed, commercially available film. Overall equipment arrangements for the systems are essentially similar, consisting of a barge-tug arrangement on which is placed the handling equipment particular to the system in use (Figures 5-7 and 5-8). Preformed, commercially available film systems were found to be relatively inexpensive and easy to apply.

Basically, a film up to 20 ft wide would be deployed. Widmer and Epstein indicated that it could be deployed in "moderate" depths, preferably over relatively flat or gently rolling terrain. Obviously, large or jagged obstruction would complicate the situation. Subsurface equipment would be mounted on an area extending from a crane on the barge to the bottom (Figure 5-7). Rolls of material would be stored on the deck of the barge. Subsurface equipment for the hot melt and coagulable polymer systems would be similar.

Several problems arise with such a system. First, gaseous production in the sediments beneath the film would require a mechanism for dispersing the gas or having the sheeting bubble-up.

In Japan, barge-mounted deep chemical mixing systems for mixing cement and lime with fine-grained cohesive sediments have been developed to aid in stabilization of harbor bottoms for construction purposes. Both the Deep Cement Mixing Method (DCM) and the Deep Lime Mixing Method (DLM) operate in an essentially similar manner: columns of mixed sediments are formed which harden and increase load-bearing characteristics of the bottom. The DCM uses portland cement as a mixing agent, while the DLM uses quicklime. Application of either of these methods to covering and stabilization of spilled hazardous materials can be

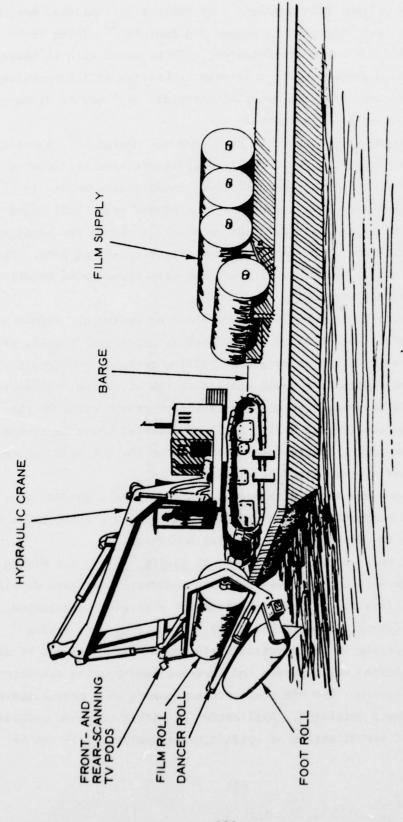


FIGURE 5-7. DECK ARRANGEMENT FOR BARGE-MOUNTED APPARATUS FOR PREFORM FILM OVERLAY SYSTEM.

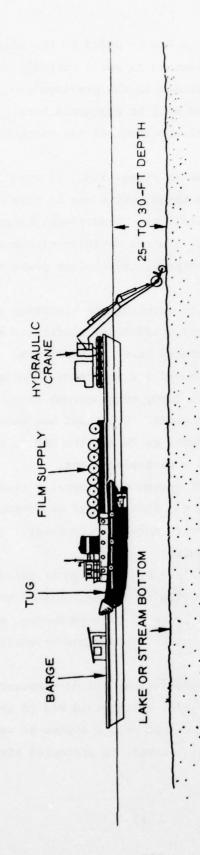


FIGURE 5-8. OVERALL FILM OVERLAY EQUIPMENT ARRANGEMENT.

foreseen, and chemical additives can be added to the mixing material which will enhance its effectiveness in spill control. As with the roller deployment systems discussed in the previous section, only the hardware and application method will be discussed here. Further attention to the suitability of various chemicals and costs will be paid in Task IV.

The DCM apparatus is shown in Figure 5-9. It consists of a number of injector pipes mounted on a barge, which are in turn connected to mixing pipes which enter the sediment. Traditional barge mooring and movement methods can be used to control position within the spill area. Thus, laser control, channel markers, and similar positioning methods could be used.

The process is completed by lowering the operating mixing apparatus (mixing blades are located within individual shafts) to required depth and injecting a cement-based slurry into the sediments. Mixing blades are reversed and the shafts removed and relocated. Sediments are generally treated in pile form, wall form, or honeycomb form, thus creating a composite of mixed and unmixed areas. Treatment has occurred on land to depths of 8.5 m, with harbor tests to 30 m. The DLM is essentially similar, but uses quicklime as a hardening agent.

While discrete segments of bottom are generally treated in this manner, it appears feasible that a system could be devised along the same lines to achieve a shallower, more uniform cover. Land-based tests have achieved such uniform results.

The system will be constrained by its barge-oriented configuration, which would limit offshore activity to periods of good weather. Transportation to spill sites would again be time-consuming, especially if low numbers of apparatus were built. This might necessitate emergency pretreatment of the spill.

This system, then, holds promise, as its development in Japan has shown. Prototypes have been built, which would aid in the rapid transfer of technology to the U. S. should such a system be warranted here. Use would generally be limited, however, to protected river and harbor scenarios.

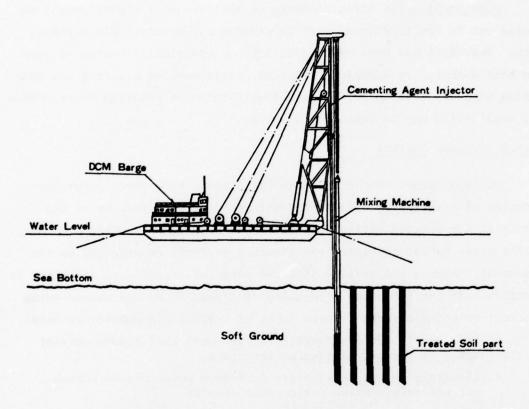


FIGURE 5-9. CONSTRUCTION BY DEEP CHEMICAL MIXING (DCM) METHOD.

A plough-type apparatus, designed to turn under spilled materials, is conceptually possible. This would consist of a device similar to a plough towed behind a tug or other suitable workboat. The spilled material would be turned under beneath sediment. This option is considered to have very little potential due to the almost certainly severe turbidity and resuspension expected to be caused by the operation.

Hand application (from rowboats or similar small craft) cannot be ruled out in confined areas such as riverbanks, nonnavigable streams, etc. Bentonite has been applied to lagoons and similar bodies of water in this manner, for example. In Sweden, early work on covering was done using hand application. Problems of uniformity of covering and slowness of application may be expected, however.

5.4.3 Erosion Control

Two approaches can be taken in the attempt to control scour or erosion of a burial material: (1) selection or modification of the material for erosion resistance, or (2) deployment of submerged structures after burial to reduce the scouring currents experienced by the material. Approaches dealing with the material itself were described in Section 5.3; the following discussion describes those approaches using current-reducing devices. Three types of devices are considered here:

- o Small-scale devices (artificial seaweed) that reduce current speed at the sediment/water interface.
- o Floating, moored breakwaters to reduce wave-induced bottom current surges which could cause erosion.
- o Dikes or fixed breakwaters that divert currents around the spill area and/or reduce wave-induced bottom current surges.

5.4.3.1 Artificial Seaweed. Considerable research has been done in The Netherlands on erosion control of submerged sediments. One focus of the Dutch research has been the use of artificial seaweed. The cited work has shown that polypropylene strands, anchored on the bottom, reduce currents in the proximity of the bottom. It is logical to expect that a similar velocity redistribution could be achieved by other means, such as rigid rods or pickets. Some bending is probably desirable, however, because a natural or artificial array of grasses reduces

current by a combination of mechanisms, including increased bottom drag and absorption of energy in the bending process. Wayne ⁵⁷ has found that natural sea grass, <u>Thallassia testudinum</u>, can reduce wave-induced bottom currents by 20 percent. The available data are not sufficient to predict for a given set of circumstances the quantitative current reductions that artificial sea grass emplacements would produce, however. Similar approaches have been successful in combatting scour around drilling platforms in the North Sea oil fields. ⁵⁸

- 5.4.3.2 Floating Breakwaters. In cases where erosion may be caused by wave-induced bottom surge, floating breakwaters can reduce the surge by reducing the surface wave energy. Assessment of this approach must be site specific and include factors such as:
 - o Design wave height,
 - o Depth of water,
 - o Bottom surge likely to be caused,
 - o Hazards to navigation,
 - Relative effect of wave-induced surge compared to bottom currents caused by other factors, and
 - o Effectiveness of candidate breakwater designs.

If the waves of concern always come from one direction (e.g., if the spill site is near the shore of an ocean or large lake), the spill site need only be protected from that direction. On the other hand, if the site is subject to waves from any direction, complete encirclement may be necessary.

Costs of a floating breakwater made from specially manufactured components are difficult to assess because the concept is still in the research stage. ⁵⁹ If, however, the breakwater were made from tethered, discarded tires, as was recently done in Lake Erie, costs could be very low.

5.4.3.3 Dikes/Fixed Breakwaters. Dikes and fixed breakwaters are traditionally used as shoreline protection measures and also find

applicability in the confinement of dredged material. They can serve as a wave and current diversion, reducing bottom currents and surges over the spill and thus preventing erosion of the spill or its cover. The applicability of in-water and submerged dikes to containment of covering material is discussed below under dispersion control; that discussion is also generally applicable here.

5.4.4 Dispersion Control

Retention and covering of a spill of hazardous material can be enhanced using dispersion control techniques. These techniques (curtain barriers, retaining dikes, and submerged trenches) can be used to confine spilled material, control dispersion of covering material along the bottom during application, and lower turbidity in the water column during application.

In a study performed for the Corps of Engineers, ⁶⁰ the potential for silt curtains as a turbidity reducing device in dredged material discharge has been evaluated. A physical barrier system for control of hazardous material spills has also been reported. ⁶¹ A study was performed for the Canadian Department of the Environment which addressed the problem of dispersion control. Submerged dikes, submerged dikes plus curtain turbidity barriers, and plastic conical "umbrellas" were all suggested as possible control techniques.

Labyrinth-type barriers (possibly as a special application of turbidity control curtains) and strategically located trenches can be envisioned for dispersion control. As noted in Section 5.4.2, trenches and submerged dikes have potential for stopping mudflows, and the turbulence generated from a labyrinth device could also impede a mudflow's progress.

5.4.4.1 Curtain Barriers. Silt curtains (Figure 5-10) have frequently been used for turbidity control in dredging, but have also been used in such construction activities as pile driving and airport and highway construction. They basically consist of a boom-supported fabric barrier ballasted at the bottom and backed by a tensioning line approximately 1/4 to 1/3 of the way to the skirt bottom. They are

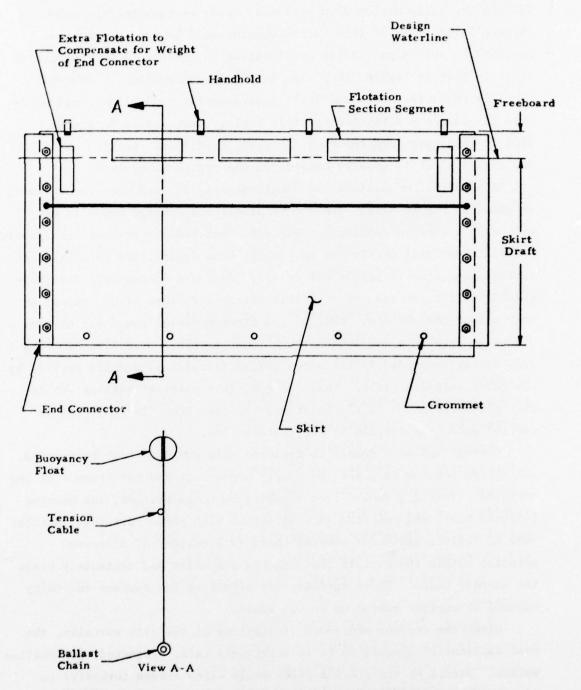


FIGURE 5-10. CONSTRUCTION OF A TYPICAL SILT CURTAIN SECTION.

secured to the bottom or land with suitable anchoring or mooring devices and are typically deployed in a closed, open, or maze configuration (Figure 5-11). Any of these arrangements could be used as shown or modified to suit a particular spill situation. There is no theoretical limit to curtain length (they come in 100-ft subsections). However, handling characteristics and local environmental conditions would determine lengths on a situation-specific basis. Curtains in excess of 2000 ft long have been reported. Curtain drafts are reported up to 20 ft, though 10 ft is usually considered the practical maximum.

A number of mechanisms are simultaneously at work near the curtain, as shown in Figure 5-12. The dredge pipeline discharge normally used with such a curtain consists of material that readily settles out (sand), material that will settle out in a short time (silt), and material that takes a long time to settle out (clay). Sand and coarse silt fractions quickly settle out and are of little interest to this study, except as they affect the curtain. Most of the finer material moves out of the discharge area in a mudflow on the bottom; however, some fine silt and clay become suspended in the water column (turbidity) and are carried by the water velocity field. While some of this material settles out inside the curtain due to flocculation, the remaining fine material is carried under the curtain by the current flow.

Current and wave damage to deployed silt curtains have been noted, and a high premium is placed on proper deployment and maintenance of the curtains. Tearing, damage from scraping on rough bottoms, and mooring failures have been reported in conjunction with these curtains. Another mode of failure can occur whereby there is a buildup of dispersed material within the curtain that reaches the skirt and ultimately drags the curtain under. These curtains are effective for surface turbidity control at current speeds up to 0.5 knots.

Given the current and depth limitations of the silt curtains, the best application appears to be in relatively calm, protected, and shallow waters. Waters of too great a depth would allow excess turbidity to flow under the curtain, while unprotected or high current areas would increase chances of catastrophic failure of the curtain, as well as

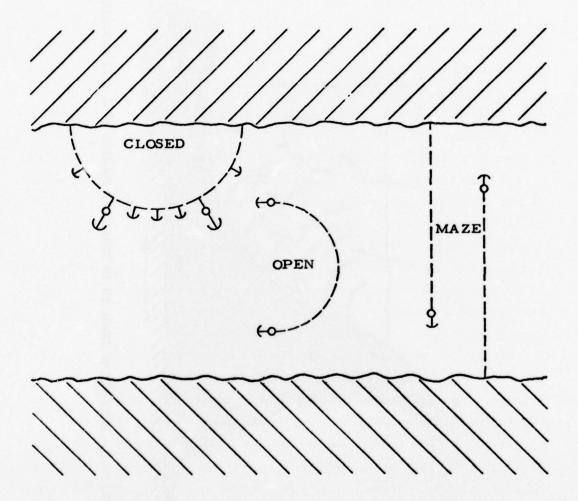


FIGURE 5-11. TYPICAL SILT CURTAIN CONFIGURATIONS.

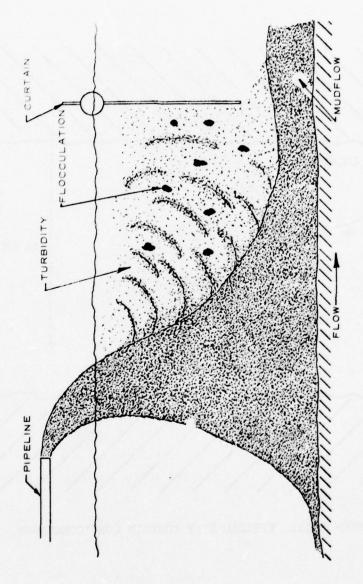


FIGURE 5-12. MECHANISMS INVOLVED IN TURBIDITY CONTROL BY A SILT CURTAIN.

reduce its turbidity control efficiency.

A combination of a hopper barge, curtain, and submerged dike arrangement has been suggested for open-water use. ¹⁸ A diagram of the system is shown in Figure 5-13. This arrangement consists of a catamaran vessel supporting a curtain. The vessel is moored within a submerged dike positioned around the spill area which would retain cover on the bottom. A hopper barge is positioned within the catamaran and deposits its load through the curtain, which in turn guides the material to the proper location on the bottom. Problems with turbulent impact on the bottom are possible as well as difficulties in fabricating and deploying the curtain.

A concept similar to the silt curtain has been developed for the EPA. 62 The system differs from the silt curtain largely in that it extends completely to the bottom of a waterway (25-ft maximum). The barrier consists of a flexible fiber-reinforced plastic. Buoyancy is provided by an air flotation collar and a water isolated bottom seal. Explosive embedment anchors are used to secure the barrier to the bottom. The system was designed to be used in currents up to 2 knots and comes in 200-ft lengths, which may be joined together. Delivery to a spill scene would be by truck.

Only one of the above systems has been built and tested to date. Field results appear mixed and modifications to the system are expected. In some instances (Bear Lake, Utah), the system functioned well. In others (Sugar Grove, West Virginia), explosive anchors were damaged upon deployment, while total deployment time was 6 hr. Difficulty in handling is evident. Thus, the system, while showing some promise, does require additional development to be useful. In any event, it is obvious that application will generally be limited to quiescent and shallow waters. The system will not be useful in open waters in its present state of development.

5.4.4.2 Dikes (In-Water and Submerged). In-water and submerged dikes would find their greatest application in surrounding a spill area and permitting controlled covering of it to whatever depth might prove necessary. The presence of the dike would permit efficient use

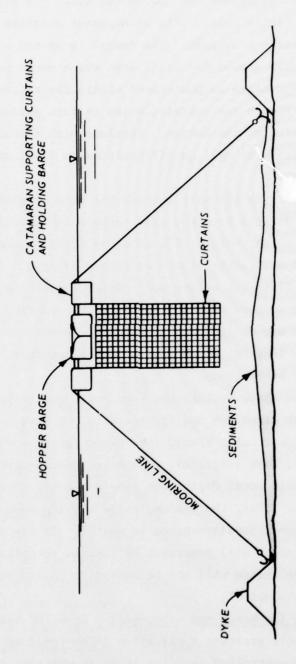


FIGURE 5-13. PROPOSED DIKE UNDERWATER DISPOSAL TECHNIQUE.

of covering material and there would be relatively little dispersion of the material into unwanted areas. Dispersion of polluted material prior to covering would also be reduced.

The WES⁶³ has conducted a study on the confinement of dredged material which included discussion of in-water dikes. Diking of disposal areas in water has been suggested as one solution to the problem of dredged material disposal. Several such areas have been built, but are in shallow water, and the dikes are exposed. Such in-water dike techniques will likely find applicability to spills in shallow water portions of rivers and harbors—alongside a riverbank, for example.

In-water dikes are typically constructed of granular material with stone protection against wave and current action. Materials are local whenever possible. Hydraulic pumping, dragline or clamshell, and/or land-based or barge dumping may be used to construct the dike.

Submerged dikes, while not frequently used in the field, may prove useful in spill containment and covering. Field and laboratory experience tend to indicate the potential effectiveness of such structures. The previous section related one possible use of a submerged dike in concert with other control measures.

White 53 observed that a submerged dike could impede the progress of a mudflow. A shallow dike of approximately the same height as the thickness of a mudflow did not impede progress significantly. However, when the height of the dike was doubled, the mudflow made contact with the dike, originally flowed over it, but then fell back. As more sediment was added to the system, the layer in the dike became thicker and eventually spilled over. White's observations compared favorably with field observations on an abrupt rise in a reef by Masch and Espey. 54

A submerged dike system was attempted as a part of the Calumet River (Illinois) Pilot Project conducted by the Corps of Engineers and summarized in the report by the Canadian Department of the Environment.

In this project, clamshell dredging of the Calumet River was conducted over a 3-month period, the material being transferred to a confined temporary storage area closed at one end by a submerged dike. The dredged material was pumped from this area to a permanent land-based

location by hydraulic dredge. Water quality in the temporary storage was greatly degraded during dumping and rehandling operations, while outside the dike conditions were similar to that in the river, indicating satisfactory operation of the system. No details on construction of the submerged dike were given, though construction using a clamshell would certainly seem likely.

While data on construction of submerged dikes are generally lacking, point dumping of low liquid, cohesive materials (having a tendency to mound) could be used to construct a submerged dike around a spill in relatively deep water. Navigational problems would make this a difficult task, however, and there would always be the danger of accidentally dumping onto the spill and possibly resuspending whatever hazardous material was on the bottom.

Submerged dikes will find immediate application in relatively quiet waters, possibly surrounded on one or more sides by natural barriers, such as shorelines. Complete enclosures around a spill may be useful, allowing the dike to act as a containment barrier for both hazardous material as well as emplaced cover.

5.4.4.3 Trenches. Trenches have been suggested as a possible way to impede the progress of mudflows. White 53 observed that when a mudflow reached a trench, it was broken up to an extent by separation at the edge. Considerable deposition of mud was noted in the trench. Field investigations by Masch and Espey 4 appear to substantiate these findings, as mudflows were noted falling into and being retained by dredge cuts designed as sediment traps. They termed such a trap "very effective" in intercepting and holding dredged sediments. It is expected that a trench would be just as effective in retaining covering material if properly sized and placed. Type and amount of covering material, frequency of covering activity, and local topography and bottom currents should be considered when placing and sizing trenches. No single rule of thumb can be given. For example, in locations with unidirectional flow, a downstream trench will be most advantageous, while in cases of random currents, an enclosed circle might be most useful.

5.4.5 Navigation

Navigational accuracy is a key to the successful covering or dredging (Chapter 4) of hazardous material spills—especially in open waters. Navigational difficulties and accuracy of material placement have been mentioned in conjunction with hopper dredge pump—down and spray boom application methods. These problems are also present in deep water point dumps, when subsurface motion on the part of the dumped material further degrades the accuracy of material placement. Spills in more confined areas, such as ports and rivers, are not expected to pose as severe a navigational difficulty as open—water spills due to the relative abundance of nearby fixed landmarks.

Navigation in the spill area will be greatly enhanced if the area to be covered is laid out with marker buoys. In some instances, the offending vessel will have remained in the area of the spill or may have sunk in that location. Spills at or adjacent to a pier will post very few location problems. Physical observations, bottom sampling, and water sampling will assist in defining an area to be covered, once its general location has been established. Open-ocean sites will be correspondingly more difficult to fix, due to generally deeper water, higher currents, fewer visible aids, and so forth.

Hopper dredges and oceangoing tugboats (used in conjunction with barges) will have little trouble reaching an open-water spill area once marked. A combination of visual, electronic, and acoustic navigation aids (such as lights, Loran-C, cubic autotape, depth finders, etc.) will be able to place the vessel to accuracies of better than 3 ft within a fully marked spill area. Problems of placement will, at this point, become important. Several of the more likely problems to be encountered include: oscillation of point-dumped material on the way to the bottom, inadequate control over dragarm location in pump-down operations, and current effects on the descent of particles coming out of a sand-spray system. Poor visibility, high sea conditions, and other factors will render placement in open-water areas even more inaccurate.

Equipment such as hydraulic pump-down barges or pipelines

discharging into a spill area will not need the precise navigation of, say, a hopper dredge or clamshell dredge, especially if a submerged discharge-induced mudflow is used as the covering mechanism. In these cases, the biggest problem will be to confine the covering material to the spill area. Any bottom-dumping scows or barges used in a confined spill area will be positioned using either the assisting tug's navigational aids, visual aids, or spill location buoys. If the water is relatively shallow, sufficient accuracy of placement should be achieved. Divers, fathometers, echo sounders, side-scan sonar, and similar devices can be used to check the completeness of cover in all of the above cases.

Tables 5-5 - 5-7 present summaries of available electronic navigation and distance measuring techniques. Table 5-5 lists available electronic navigation techniques and groups them into three broad categories. Group 1 includes those systems with accuracies of + 1 to 2 miles which are typically used to meet the general navigation needs of oceangoing vessels requiring coarse positioning. These may have limited applicability to ocean spills. Group 2 has accuracies of + 100 to 600 ft. These are used for offshore surveys, bottom mapping, and transit through congested areas. They also would be applicable to open ocean and other open-water areas. Group 3 is accurate from + 3 to 100 ft. These systems are used in predredging surveys and other applications requiring very high precision or the need to return to the same spot. Another group (not shown) is available with + 1-ft accuracies. This degree of navigational accuracy, however, would generally be negated by environmental conditions and the inherent inaccuracies of the placement technology.

It is understood that all of these systems can be used in conjunction with more traditional navigation: visual aids such as lights and buoys, charted landmarks, radar ranges, etc. Acoustic measures such as fathometers, echo sounders, and acoustic dopplers can be used to further enhance navigational ability.

Table 5-6 shows a comparison of distance measuring techniques, and Table 5-7 shows the parameters of interest for various distance measuring

Table 5-5 Electromagnetic Navigation Systems

Estimated Accuracy +ft	System	Approximate Range nautical miles	Comments
		GROUP 1	
0009	Loran A	009	Being phased out
0009	Omega	Worldwide	Low operating costs; land identification problems; diurnal shifts
0009	Standard Decca	250	Easy to use; insufficient coverage; subject to skywave interference
		GROUP 2	
009	Basic Satellite	200	Negligible skywave error; requires correction for ship's speed
50-150	Loran C	1200	Accurate; easy to use; insufficient coverage and charts
25-200	Decca Two-Range	175	Circular plot-single user; error increases with range; high degree of pattern ambiguity
120-300	Integrated Satellite System	Worldwide	Only available every 110 min; requires gyro compass and digital computer; atmospheric corrections, etc., must be made
15-250	Electronic Position Indicator (EPI)	250	Error depends on distance and angle; requires ship and two shore stations; negligible error of intersecting angles between 30° - 150°
100-250	Shoran	25-75	Weather can reduce range; operating frequency unacceptable

(Continued)

Table 5-5 (Concluded)

Estimated Accuracy +ft	System	Approximate Range nautical miles	Comments
25-150	LORAC	135	Requires three shore stations; continuous tracking; multiuser capability; needs lane identification
10-150	Raydist "DR-S" & "T"	150	DR-S circular geometry and only small geometric dilution, but suffers from rangelane ambiguity; I does not require transmitter on platform.
		GROUP 3	
80	Precision Radar Unit	Line-of-sight (maximum)	Short range; operates in microwave band; complements ship's standard radar
10	Motorola Mini-Ranger	Line-of-sight	5-gHz frequency range
10	Decca Trisponder	Line-of-sight	9.5-gHz frequency range
5	Plessey Tellurometer	Line-of-sight	3-gHz frequency range
3	Cubic Autotape	Line-of-sight	3-gHz frequency range

Table 5-6 Comparison of Distance Measuring Techniques

Energy	Technique	Velocity	Range	Resolution	Accuracy
Radio					
LF	Phase	*SN	1000 miles	1 mile	
色	Pulse	NS	100 miles (not line- of-sight)	300 ft	
HF	Phase	NS	100 miles (not line- of-sight)	3 ft	
3	Pulse	NS	100 miles (line-of sight)	0.1 m	
3	Phase	NS	100 miles (line-of sight)	0.1 m	+ 1 B
3	Doppler	NS	Unlimited	0.1 ft/sec	+ 0.1 percent of distance traveled
Optical	Pulse	NS	40 miles	1 ft	
	Phase (Modulation)	NS	2 miles	0.01 ft	
	Phase (Coherent)	NS	200 ft	1 in.	
	Doppler	NS	Unlimited	0.001 ft/sec	
Acoustic	Pulse	10 mph	12 miles	1 ft	
	Phase		12 miles	1 ft	
	Doppler	100 mph	Unlimited	0.1 ft	+ 0.1 percent of distance traveled
Inertial	Acceleration	Unlimited	Unlimited	0.1 ft/sec ²	<pre>+ 1 mph of time traveled</pre>

* NS = Not significant.

Table 5-7
Distance Measuring Equipment for Static Applications

Company	Model	Range	Energy	Resolution	Accuracy	Weight	Cost
Spectra Physics	Geodolite 30	40 miles	Optical	1 mm	$\pm 2 \text{ mm} + 1 \text{ ppm}$	150 lb	\$50,000
K&E	Microranger	3 km	Optical	1 mm	5 mm + 2	13 1b	4,000
(Laser Systems)	Ranger II	4 miles	Optical	1 mm	+ 5 mm + 2 ppm		8,200
	Ranger III	8 miles	Optical	1 1	5 mm + 2	36 1b	8,700
	Rangemaster	40 miles	Optical	1 1	+ 5 mm + 1 ppm		18,000
AGA	Geodometer-6B	20 km	Optical		+ 5 mm + 1 ppm		7,300
	Geodometer-8	50 km	Optical		+ 6 mm + 1 ppm	36 15	16,000
	Geodometer-700	3 miles	Optical		ı		15,000
	Model 76	3 km		1 111	+10 mm + 1 ppm	20 1b	4,100
Zeiss	SM-11	2 km	Optical		+10 mm	36 1b	13,500
	Reg Elta 14	2 km	Optical		+10 mm	36 1b	27,000
Wild	DI-10 Distomat DI-150 Distomat	2 km	Optical Microwave		+10 mm		6,200
Cubic	Cubitape Electrotape	2 km 50 km	Optical Microwave		+ 5 mm + 10 ppm +10 mm + 3 ppm	12 1b	4,000
Hewlett Packard	3800 B	2 km	Optical	2 mm	+ 5 mm + 7 ppm		4,200
Tellurometer	MA-100 CA-1000	2 km 6 miles	Optical Microwave		+ 2 mm + 1 ppm	30 1b 7 1b	4,000
	MRA-3	50 km	Microwave		mm + 3	40 1b	
	MRA-4 MRA-101	50 km 65 km	Microwave Microwave		+ 3 mm + 3 ppm +20 mm + 3 ppm	40 1b	3,500
Seintrex	Akkuranger Mk II	1 km	Optical	3 mm	+10 mm + 10 ppm		
Sokkisha	SDM-3	1 km	Optical		+10 mm	40 1b	
aus Jena	EOK-2000	2 km	Optical		+10 mm		
Applied Devices	Micro-Surveyor Model 99	50 km	Microwave		+15 mm + 4 ppm	112 16	

equipment. It is clear that for purposes of positioning the dredge or covering apparatus, the technology and equipment are available. Accuracies of a few feet should be possible, leaving control over covering as the critical problem.

5.5 BURIAL SYSTEM EVALUATION

Assessing the feasibility of burying a hazardous chemical on the bottom involves the following determinations:

- a. Compatibility of cover material with spilled material,
- Compatibility of cover material with spill scenario, including quantity/cost considerations,
- c. Suitability of emplacement method to spill scenario, and
- d. Compatibility of cover material with emplacement method.

Only the third consideration—emplacement method vs. spill scenario—is considered amenable to any sort of numerical rating. As with the dredge evaluations, the emplacement method evaluation matrix (Table 5-8) must be considered as a qualitative guide to each system's overall potential for the various spill scenarios and not as an absolute, objective measure. The evaluations presented in Table 5-8 must be used in full cognizance of the technical information presented for each system in previous sections. Unlike the dredge evaluation matrices wherein one matrix was provided for each of the four environmental settings and each matrix included numerous individual weighted rating criteria, the burial emplacement system matrix is contained in a single table wherein each of the eight systems is given a single subjective score (0 = worst, 10 = best) for each of twelve spill scenarios. In arriving at the scores, the following factors were considered:

- o Physical compatibility of system with the environmental setting (e.g., a submerged dredge pire system cannot be used on a land spill).
- o Effectiveness and inherent accuracy of emplacement technique in given setting (e.g., pump-down systems would be superior to point dumping, especially in deep water or those with currents).
- o Efficiency of emplacement technique from standpoint of area to be covered, time, and cost of probable material used.
- Likely availability of necessary equipment and ease of placing into operation.

The job size criterion apropos to burial is the area of the contaminated zone that must be covered, and again, spill size (quantity of hazardous material spilled) per se is not used in the matrix to discriminate between small, medium, and large tasks. The areas chosen to set off the three job sizes are: less than 1 acre--considered to be the practical upper limit for hand emplacement of burial materials; 1 to 40 acres--a convenient range for which the upper limit of 40 acres would require about 33,000 cu yd of in situ material to cover to a depth of 6 in. (about eight medium size hopper dredge loads assuming perfect coverage); and greater than 40 acres. These breakpoints may be roughly comparable in terms of time and effort to the dredging job size breakpoints of 1,000 and 200,000 cu yd. The quantity of hazardous material spilled may be an important consideration as well, especially when using reaction stoichiometry to estimate quantities of active materials to apply.

In the matrix, the last three columns serve to identify which of the three basic types of bulk cover material (inert sediment or dredged material, inert material obtained from land-based sources, and active chemicals) are compatible with each emplacement system.

Compatibility of cover materials with spilled chemicals are not given numerical ratings, but are summarized in general terms in Table 5-9.

Cover material and spill scenario compatibility is not a major concern except that, where currents or high turbulence are present, easily scoured materials would not be suitable.

All four of the necessary determinations are addressed to the extent possible in Tables 5-8 and 5-9. A soundly based burial response must carefully consider each of the four factors.

Burial Emplacement System Evaluation Matrix All Spill Scenarios Table 5-8

	7	Land and	P										Cover	Cover Materia	rial
	Nonnav	igable	Nonnavigable Waters	R	Rivers		Ports	and H	Ports and Harbors	Oper	Open Waters	srs	Suit	Suitability	ty
	s	z:	ادا	SI	ΣI	11	ωI	Σl	1	s)	ΣI	ы	LS	11	AC
Hand Application	1	-	1	3	7	-	4	7	1	3	٦	-		×	X
Land-Based Construction Equipment	10	10	10	-	1	1	6	m	E	0	0	0	×	×	×
Surface Discharge from Dredge Pipe	4	2	9	7	8	4	m	4	2	7	3	4	×		
Spray-Boom System on Hopper Dredge	0	0	0	-	п	-	4	2	9	8	4	2	×	×	×
Submerged Dredge Pipe	0	0	0	1	∞	6	7	00	6	2	9	7	×		
Pump-Down from Barges and Scows	0	0	0	œ	œ	7	œ	∞	7	2	2	4	×	×	×
Pump-Down from Hopper Dredge	0	0	0	-	1	7	œ	∞	7	6	œ	7	×	×	×
Bottom Dump from Scows and Barges	0	0	0	S	4	3	S	4	د	4	8	2	×	×	×
Bottom Dump from Hopper Dredges	0	0	0	-	-	н	'n	4	6	S	4	8	×	×	×

Notes:

S = Small - less than l acre.
M = Medium - l to 40 acres.
L = Large - greater than 40 acres.
LS = Local sediment (dredged material).
I = Land-based inert.
AC = Active chemical.

Table 5-9
Recommended Covering Materials for Specific Chemicals

Spilled Chemical	Recommended Cover
Aluminum Fluoride	Inert*
Calcium Fluoride	Alumina
Aspha1t	Inert
Barium Carbonate	Inert Calcium Sulfate (Gypsum) Ferric Sulfate
Calcium Hydroxide	Inert Sulfates Carbonates-limestone
Lead Arsenate	Inert Basic materials-limestone
Phosphorus, Red or White	Sulfur Pyrite Solid oxidizing agents (e.g., potassium permanganate)
Sulfur	Inert Basic materials-limestone
Organic Chemicals	Inert materials with low perme- ability and high adsorptive capacity (clays)

^{*} Preferably naturally available materials similar to bottom sediments at the spill site.

6.0 OTHER HIGH POTENTIAL TECHNIQUES

6.1 INTRODUCTION

This chapter provides information and an evaluation of high potential containment and amelioration response techniques (other than dredging or burial) applicable to the hazardous chemicals included in this study. These techniques are generally assumed to be temporary, as the first choice will usually be to remove the material from the spill site. In cases where removal is not practical, these techniques may be the only mitigating measures readily available.

Included in this chapter are a number of underwater containment and burial techniques mentioned in Chapter 5, but not sufficiently developed to constitute full consideration there. This chapter provides more detail and discussion on these techniques including the use of special and some untested covering materials. Also included in this chapter are discussions of techniques such as adsorption, chemical reaction, biodegradation, and dispersion. Many of these techniques are largely untested in their application to hazardous materials that sink. The discussion of each technique in this chapter consists of a description of the technique, examples of past usage relevant to hazardous material spill control, any available information as to cost and availability of the technique and required materials, impact on biota, and likely spill scenarios in which the technique could prove useful.

A final summary section is included in this chapter addressing response appropriateness as determined by the chemical spilled and response appropriateness as determined by the spill scenario. It was deemed inappropriate by the authors to develop a numerical rating matrix for the techniques discussed in this chapter because many have not been tested to date and are, in any case, not directly comparable. The summary tables can provide an indication of potential applicability of the response techniques to catagories of chemicals and spill scenarios.

6.2 CHEMICAL COMPATIBILITY

This chapter relates the 70 sinking hazardous chemicals to a variety of potential response techniques. The classification of the chemicals according to their physical and chemical properties was originally presented and discussed in Chapter 2. The information in this chapter is organized so as to be compatible with the chemical background information given in Chapter 2.

The techniques discussed in this chapter cover the range of chemicals under study. In many cases the techniques are somewhat chemical specific. Such information is discussed in each section as it pertains to a particular technique and is summarized at the end of the chapter. It should be noted that many of the techniques are untested on the chemicals under study. The potential for success for these techniques was developed on the basis of applicability of the techniques in related situations or in theory. Extensive verification and development work will be necessary on many of the response techniques presented in this chapter.

6.3 CONTAINMENT

The initial phase of any response to a spill will include consideration of possible measures for spill containment. Several measures for containing the dispersal of covering material have been covered in Chapter 5, including curtain barriers, dikes, trenches, and others (including designs for control of mudflows). These methods should find application in the containment of spills as well, especially those of liquids. In all cases, containment of a spill will make response easier and may permit the use of difficult-to-control materials (e.g., unbagged activated carbon or ion-exchange resins). With containment, neutralizing chemicals, such as oxidants, could be more safely added and aeration efforts could be better controlled.

6.3.1 Curtain Barriers

Information has been gathered on two generic forms of curtain

barriers: one type designed specifically for control of turbidity from dredged material discharge (the silt curtain), and the other specifically intended for use in containment of hazardous materials spills. The silt curtain, discussed in Chapter 5, is not considered promising for confinement of sinking hazardous materials, as it is not designed to reach the bottom of a body of water. This would allow the sinking chemical to disperse underneath the curtain barrier. The hazardous material barrier, though not without problems, has been specifically designed for use in cases such as those under consideration here. Further discussion will be centered on this device.

As was indicated in Chapter 5, the hazardous material barrier was developed for the EPA. Individual barrier units (which may be joined together) consist of a 200-ft-long section of flexible, fiber-reinforced plastic, with buoyancy provided by an inflatable flotation collar. There is also a water-inflated bottom seal, secured by explosive anchors. It is claimed by its manufacturer (Samson Ocean Systems, 99 High Street, Boston, Mass.) to be effective in 1-knot currents, 40-knot winds, and 6-ft waves. There is a 25-ft depth limitation. The barrier was designed to be effective in spills of a number of hazardous chemicals. Among these are aldrin and DDT, which are both under consideration in this report. An artist's conception of a deployed barrier is shown in Figure 6-1.

Deployment of the barrier would require a crew of a minimum of five men, portable air compressor(s) and integrated water pump, and one or two outboard powered boats or inflatable rubber rafts. The system was designed to be transported in a small truck, helicopter, or similar conveyance. A typical deployment sequence (Figure 6-2) follows:

- o Transport barrier system to the site of spill.
- o Inflate and activate boats.
- o Survey site and locate source of pollutant. If barrier is submerged, position marker buoys.
- o Make up a barrier length compatible with the size of the barrier and spill.

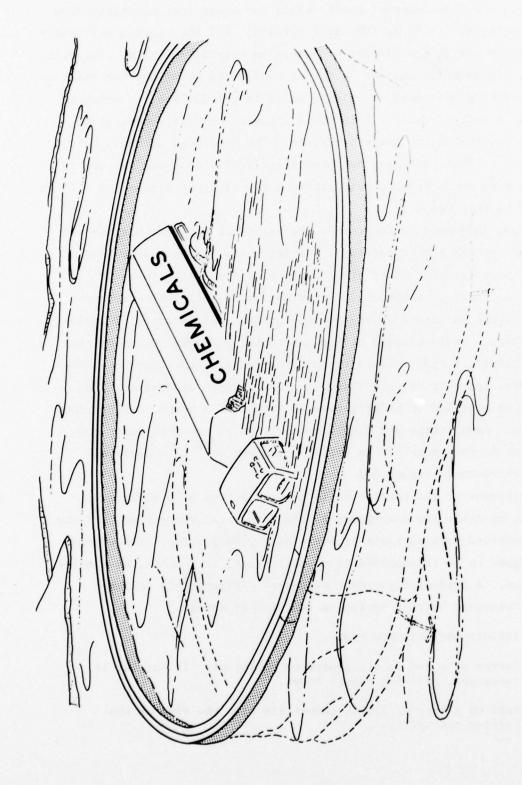
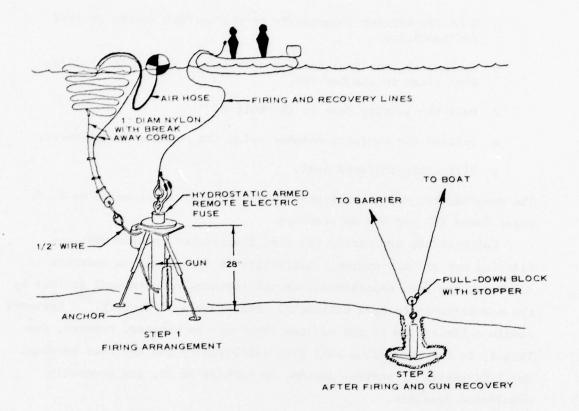


FIGURE 6-1. DEPLOYED HAZARDOUS MATERIAL BARRIER.



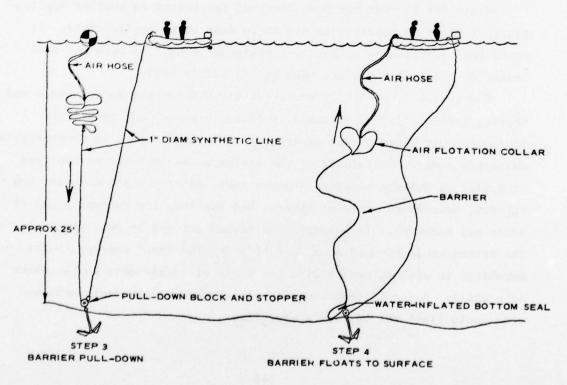


FIGURE 6-2. BARRIER DEPLOYMENT PROCEDURE.

CONTRACTOR OF THE STATE

- Moor the barrier temporarily on the surface in the desired configuration.
- o Emplant the vertical holding anchors and attach the pulling down lines to the barrier.
- o Pull the barrier down to the bottom.
- o Inflate the buoyancy chamber using the portable compressors.
- o Fill water-inflated seal.

The manufacturer claims transportability of individual units by U. S. Coast Guard HH2 and HH3 helicopters.

Currents are apparently the most significant problem when considering use of this system. Difficulty of deployment in currents of 3/4 knots has been experienced, though training of personnel is felt by the manufacturer to have eliminated much of this difficulty. Currents remain a limitation to the maximum depth of the barrier, however, due largely to the tremendous sail area exhibited by the deployed barrier. Small increases of barrier depths, to perhaps 30 ft, are presently considered feasible.

While the barrier has been designed for bottom to surface application, it might be possible to use it in deep water applications. It would then function as a "bottom-containment boom," in much the same manner as floating booms are used on oil spills today.

The system is presently quoted at \$65,000 for the basic module and mooring tackle. Air compressors, inflatable rafts, and ancillary equipment must be purchased separately. Only one system is presently in existence today. Usefulness of the system would probably be confined to spills in quiescent waters (nonnavigable waters; shallow coves; low current, near-shore areas of rivers; and shallow, low current areas of ports and harbors). It has not been tested for use in open waters. The system could be used as a part of a "strike team" concept, being purchased in advance and readied for rapid air deployment in the event of a spill. A significant time lag could occur before deployment and this would limit the barrier's usefulness.

6.3.2 Dikes (In-water and Submerged)

Dikes could be used to retain spills of sinking hazardous materials, especially those liquids that might have a tendency to spread by bottom flow. The application of dikes to the burial of solid sinking hazardous materials has been previously discussed in Chapter 5. Literature uncovered as a part of that effort 18,53,54,63 concentrated on prior application of dikes to confined dredged material disposal and also on their use as a barrier to mudflows occurring as a result of hydraulic dredging operations. The literature does not contain information on the application of dikes to spilled hazardous materials.

Retaining dikes would likely be confined to nearshore, shallowwater areas, though the use of dikes for open-water island construction has been practiced by the Dutch. ⁶⁴ In-water dike construction experience is limited and has generally been conducted to depths of no more than 30 ft at mean low water. Retaining dikes have historically been sloped earth embankments constructed either in the water or directly adjacent in bordering lowland areas and islands. Earth-filled cellular and double sheet pile retaining walls have also been used, but are expensive. ⁶³ One advantage of earth dikes is their potential for construction by existing dredging equipment and earth-moving equipment such as bulldozers. There is a good chance that such equipment would be available near a spill, especially if it occurs in a major metropolitan area. Materials for dike construction (preferably gravels or coarse sands) would probably be available near the site, depending again on spill location.

The feasibility of dikes for spill control decreases as the spill gets larger. Very small spills, in generally confined or nonnavigable waters, could be contained quickly and readily with no more requirement than men with shovels, a backhoe, or similar crude response techniques. As the water environment becomes more difficult to work in and the spill becomes larger, mobilization and construction times will increase, making the diking operation at some point infeasible as an emergency response procedure. The diking operation itself could begin to pose a greater

problem than the spill, through its impacts on the environment, obstruction to free use of waterways, and similar considerations. Open-water dike construction, while feasible, could fall into the above category.

Costs of diking will vary with the size of the spill. The following unit cost estimates for material (in place) were offered as a general guideline in a July 1975 report concerned with construction in Chesapeake Bay: 65 \$1.75 per yard for hydraulic fill plus \$22.22 per ton for riprap protection, \$8.40 per ton for any crushed stone and \$7.30 per ton for pea gravel used in dike construction. Auxiliary boats, dike instrumentation, and other ancillary expenses are not considered in the material costs. It is assumed that in a spill situation, a minimum of protective riprap, crushed stone, and processed pea gravel would be used, as the dike would be temporary. In this instance, bank-run gravel from nearby land sources or available coarse submerged sediments would provide suitable dike material. Bottom sediments could be hydraulically placed. Using this technique as an example, a 20-ft-high dike with a 4:1 slope would cost at least \$104 per linear foot, assuming \$1.75 per cubic yard hydraulic fill cost and no riprap, stone, or other material being used. Engineer fees, contingency costs, etc., would be additional.

In summary, dikes will find their greatest use in confined port and harbor areas, along riverbanks, and in nonnavigable waters. Construction in heavily used areas, such as channels, is not usually practical. Current U. S. experience with in-water earth fill dikes has been limited to depths of less than 30 ft. Open-water dike construction, while feasible, is generally not practical due to cost and the massive effort involved. In confined areas, the value of a dike as a control measure is greater for small spills due largely to rapidity of response and construction time allowed by a smaller spill.

6.3.3 Trenches

Trenches could act as a trap for sinking chemicals, particularly in the case of rivers or other bodies of water with predictable currents. Liquid sinking chemicals are often noted for their "pooling" tendencies in bottom depressions, and trench construction in selected locations

could take advantage of this tendency. Some solid sinking chemicals might also be carried along the bottom and collect in bottom depressions. The liquid or solid could then be removed from these trenches by dredging.

Experiments have been performed to assess the feasibility of gravity collection of immiscible heavier-than-water chemicals in streams. These experiments, performed using ethylene dichloride (liquid), indicate that gravity separation using trenches is a feasible method of controlling hazardous material spills. A slow-moving stream was simulated with continuous flow from hoses down a 2 percent grade. A 55-gal spill of ethylene dichloride was used in the simulation. It was noted that the solvent formed beads that moved with the flowing water and collected in a trench. Approximately 85 percent of the original volume of ethylene dichloride was recovered from the trench. Attempts at simulating fast flows revealed no essential change in the collection process.

The trenching method could be accomplished in the field through use of hydraulic dredges, land-based or water-based clamshell dredges, or similar equipment. An adaptation of a 50-ton plow used for placing pipelines offshore could possibly be used. The 50-ton plow would require 80 tons of pull, and the availability of vessels with that capability would be a factor, as well as transportability. The scaling down of such a concept could yield acceptable results. The choice of a trenching device would be dictated by the locale and characteristics of the spill area. Spills in flowing, nonnavigable waters could be handled by a land-based clamshell, a handheld suction dredge, or even by hand shovel if the spill were small enough. In deeper water and with larger spill areas, hydraulic dredges of increasing size could be used, making repeated passes over a trenching site to develop a trench large enough to collect all of the spilled material.

Trenches would be most useful in areas of predictable current, such as rivers, drainage ditches, canals, etc. Trenches could be located downstream of the spill, perpendicular to the direction of flow. In areas of reversing tidal flow, upstream and downstream trenches could be used. In off-channel areas of ports and harbors, and in relatively

shallow open waters (certainly up to 50 ft, the approximate practical limiting depth for hydraulic dredges), trenches could be dug completely surrounding the spill, such that movement of the spill in any direction could be arrested. Offshore pipe burial with the 50-ton plow mentioned earlier has been conducted in waters up to 500 ft deep. However, once trenched, there are no U. S. dredges available for use in waters deeper than about 100 ft, rendering such a deep trench less effective since removal of collected material could not take place. Costs would be commensurate with those for mobilization of a dredge or other equipment to the site and operation for whatever period would be required to dig the trenches. Material dredged in digging the trenches must be redeposited, incurring further costs and delay.

It should be noted that natural depressions, particularly in streams, would probably not be successful as containment areas. It must be assumed that whatever forces created the depression would also remove the spilled material that might tend to collect there.

6.4 COVERS

Covers and covering methods have been largely detailed in Chapter 5. Active and inert covering materials were discussed with regard to placement methods, in-place properties, costs, and availability. Sealing agents—such as grouts, cements, and pozzolanic material; polymer films; and gels—were given cursory consideration. In-depth discussion of those materials, however, was reserved for this chapter and are included in this section. In addition, further discussions of commercially available soil sealants and a section on other unique techniques are included.

6.4.1 Grouts, Cements, and Pozzolanic Materials

In Chapter 5 several cement-forming materials were mentioned.

Among these were portland cement, gypsum, lime, water-glass, plaster of paris, and calcium aluminate cements. Mixtures including lime plus pozzolans such as diatomaceous earth, fly ash, and pumicites were also suggested. The unique feature of all of these is that, when placed on

top of or mixed in some manner with bottom sediments, they will tend to harden and form a crust, preventing erosion and resuspension of spilled material. They are primarily applicable in this regard to spilled solids. A study conducted by Walley 67 on the erosion resistance of freshly injected grout (cement-like in nature) to flowing water (about 0.3 fps) revealed that, as a general rule, short gel or set times were crucial to successful placement of grout. This applied whether the grout was a typical suspension grout (e.g., cement-sand-water mixture) or any of the chemical grouts available. Experiments showed that the fast-setting grouts were the most resistant to erosion and dilution. Grout mixtures involving Wyoming bentonite (a thixotropic or expanding variety) were also noted as showing a "marked resistance" to erosion. The bentonite-containing grouts were noted to be immobile after placement due to rapid gelling. This finding is not expected to hold under turbulent flow conditions.

Information on in-place properties of the grouts, especially the properties related to impact on the environment, appears to be sparse. Sales literature from a number of companies involved in grouting tends to center on engineering properties of treated soil, permeability, and the like. Low levels of permeability have been obtained, though permeability will vary with the specific grout, soil conditions, and application technique. In-place grout is generally inert and is not severely affected by acids, alkalis, salts, or similar substances. However, the unset grouting mixtures themselves, especially chemical grouts, can be toxic and require special handling. ⁶⁸

There are a variety of potential grout/pozzolan delivery systems available for use. Pozzolans in their basic form could possibly be spread over the surface of the water (perhaps using a form of broadcast spreader) and allowed to sink in order to cover the bottom of a spill site. Hydration of the material prior to emplacement, followed by pressure injection, is also a possibility. It should be noted that the use of certain pozzolanic materials can impact the spill both as a chemically active cover (e.g., to neutralize acid) as well as an impermeable barrier. Limestone has a definite beneficial impact on spills

of lead arsenate while gypsum is suggested as an active covering agent for barium carbonate. Information is scarce in the areas of spreading techniques, optimum grain size of material, current limitations, and other topics necessary to devise a placement plan, even using this simple method.

Helicopter and truck transportable grouting units have been developed and these could be used in a strike-force configuration if required. These units are generally pressurized grouting systems. In the case of helicopter deployable units, mobilization could occur in less than a day. Units are available for offshore oil applications which permit the addition of carefully measured liquid additives in order to control such characteristics of the grouting mixture as density, setting time, and the friction factor of the grout, permitting use of the same basic mixture under a wide range of conditions. This would be useful in the event that selected chemicals were to be added to the grout in order to react with those spilled on the bottom or in order to configure the high-density, fast-setting grouts necessary for placement in the flowing water.

It remains necessary to devise a diffuser for use on the bottom in conjunction with pressurized grouting systems. It does not seem feasible to inject the grout into the bottom sediments, as that might tend to resuspend both sediments and spilled material. Placement on top of the material seems most feasible. A diffuser device which would lay the grout down in even bands would be most useful. This would increase the chance of providing an even, unbroken cover over the spilled area. Placement of the diffuser would be difficult though it could be checked by remote television or perhaps by divers, depending on water clarity and on the material being covered. A hydraulic crane, or other rigid positioning system, might prove to provide accurate placement and control of the diffusion head. Figure 6-3 presents a concept for a barge grouting system.

Grouting would probably find its best use as a barrier in low current areas. The most useful application would likely be in conjunction with chemical additives designed to neutralize in some manner

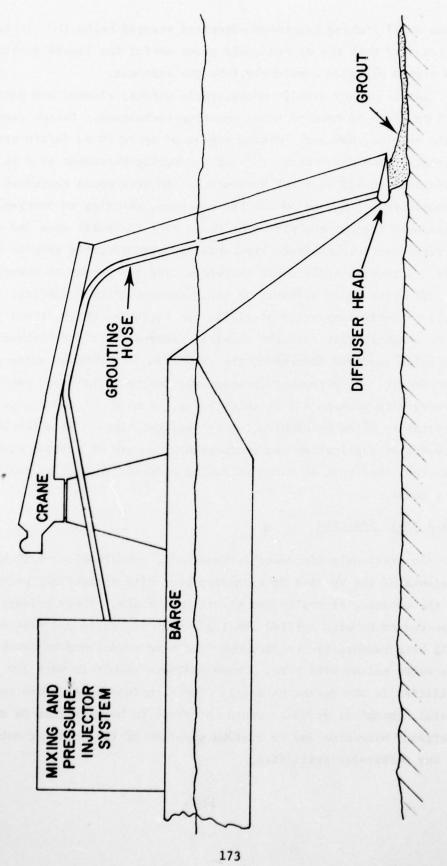


FIGURE 6-3. POSSIBLE GROUTING ARRANGEMENT.

those solid sinking hazardous materials trapped below it. It is not anticipated that the system would prove useful for liquid spills unless the liquid migrates completely into the sediment.

Spills of any size in nonnavigable waters, rivers, and ports and harbors could be handled using grouting techniques. Bottom coverage would be slow, however. Mixing speeds of up to 70 cu ft/min are claimed by one manufacturer. At a covering thickness of 2 in., this translates to 420 sq ft of bottom/min. An acre would therefore require approximately 1 hr and 50 min for coverage, assuming no overlap. Given turnaround time of the placement barge over the spill area and coverage overlap, per acre coverage time would be significantly greater than this. A 10-acre spill could therefore take over a day to cover.

Grouting would probably be semipermanent after hardening. It would probably completely sterilize the bottom on which it was placed. It is possible that once the chemical underneath it was neutralized or otherwise rendered innocuous, the grout could be removed using a cutterhead dredge. If permanent coverage was desired, the grout could be covered with perhaps a 1-ft-thick layer, or more, of indigenous bottom material to allow recolonization by resident biota. As a result of the slowness of application and semipermanent nature of certain grout/cement mixtures, they must be rated as having moderate to high overall potential as a cover.

6.4.2 Soil Sealants

As previously discussed in Chapter 5, commercially available soil sealants of the Wyoming or expanding bentonite variety may prove useful in the covering of spills and sinking materials. Their primary use is expected to be with spilled chemicals that are solid and sink or that will bond temporarily to sediments and have a tendency to leach into the water column with time. These sealants result in very low permeabilities in the sealed material. The technique could prove to be useful, though it probably would not prove to be efficient in an emergency situation due to limited supplies of the covering material at any particular spill site.

Two commercially available soil sealants for use in contaminated water or water containing significant concentrations of salt have been identified: Dowell Soil Sealant, manufactured by the Dowell Division of the Dow Chemical Company, Tulsa, Oklahoma, and Volclay Saline Seal-100, manufactured by the American Colloid Company, Skokie, Illinois. Both are Wyoming-grade (expanding) bentonite based. Their primary use is in the sealing of sanitary landfills, sewage and process plant lagoons, and similar applications. These salt-resistant grades of soil sealant can be successfully used in salt water.

Traditionally, soil sealants are best worked into the impoundment bottom prior to filling. In emergency situations, however, this will not be possible and it will be necessary to apply the mixture from the water surface at the spill site. In salt water or contaminated fresh water, it will be necessary to prehydrate the material into a slurry. (It has been applied dry by shovel from a rowboat in seal repair on freshwater reservoirs, but it is not expected that conditions favorable to this application method will occur in many emergency situations.) Mixing could be done with mechanical mixers, recirculation mixers, or portable air-driven or electrical-driven mixers using 55-gal drums. Application rates would be slow: perhaps 20 to 30 gal of mix every half hour. For higher application rates, it might be necessary to adapt a grouting mixer and pump-down device. These self-contained units can achieve up to 70 cu ft/min of coverage, as was reported in the previous section. Essentially, the same rig as used for grouting, including spreader bar, could be adapted for use with the bentonite slurry. A source of fresh water for prehydration would have to be supplied. (It should be noted that bentonite is often used in the grouts and drilling muds used in the offshore oil industry.) Hand mixing for small spills is possible, though it would be very slow.

Soil sealants would be best used in quiet waters—areas such as drainage ditches, coves, and off channel areas of ports and harbors seeing relatively little tide and current action. Wading and burrowing animals may also prove a problem, though in areas where the material is to be ultimately dredged, this will not prove to be serious. Where

long-term use of the bentonite sealant is anticipated, consideration should be given to the addition of coarse-grained material to the slurry to inhibit erosion. Information concerning impact on biota is not available. However, it should be noted that no special handling procedures for either material were noted by either the Dow Chemical Company or the American Colloid Company. Toxicity of Dowell Soil Sealant was low, and a 1-mg/ ℓ concentration in potable water is not considered toxic to humans.

Saline Seal-100 and Dowell Soil Sealants are generally available in truckload quantities (such as might be used on a spill) on 7 days notice. Costs, FOB processing plant, will run in excess of \$100 per ton, and shipping could add up to \$60 per ton to the cost, the exact amount depending on transportation mode and distance. Due to the long lead times involved, stockpiling might be necessary.

In summary, these materials will likely find their best use in protected waters. This would include nonnavigable waters and quiescent areas of rivers, ports, and harbors. Use in open waters, due largely to environmental considerations, is not recommended. Pumps and grout injecting systems are capable of pumping up to distances of several thousand feet, so water depth will not prove a significant problem. It should be noted, however, that problems in locating the spill and access by support divers will increase with depth. Use of surface applied sealants will likely be confined to very shallow water and drainage ditch spills. Considering the limitations, soil sealant usage can be considered only of moderate potential as a response technique, due largely to cost and erosion considerations.

6.4.3 Polymer Covers

Barge-mounted roller systems for the deployment of polymer film overlays were covered in Chapter 5. Information presented in this chapter is intended only as a supplement.

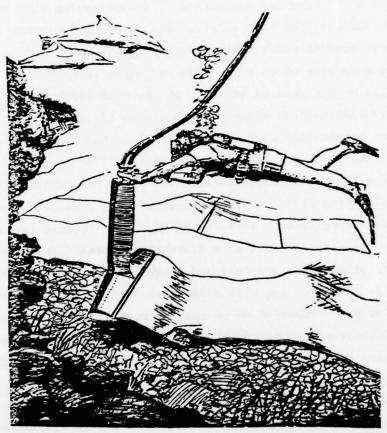
It was noted in Chapter 5 that barge-mounted deployment systems for either hot or cold application of polymer film overlays had been proposed. 47 The application systems included those for laying down

coagulable polymers (alcohol-soluble nylon), hot melt materials, and preformed commercially available films.

Early work on coatings, originally intended for ocean bottom stabilization during salvage work, was reported by Epstein and Widman 72,73 and Roe et al. 74 Epstein and Widman, 72 in discussing work sponsored by the U. S. Navy, stated that an effective ocean bottom stabilization system must operate under a wide range of environmental conditions, including a current of up to 3 knots and depth of up to 850 ft. It should also be designed to be effective in both fresh and salt water. Laboratory examinations showed that a sodium alginate system was found to produce potentially useful gels, though it had problems such as shrinkage and nonbondability. It was also subject to deterioration due to the mineral content of seawater. Two-phase pressurized dispensers, capable of laying strips of 1- and 3-ft widths, were used. No field tests were accomplished. Epstein and Widman 73 reported further on their work, including development of a dispensing system. The dispensing system was pressurized and included a two-phase faired dispensing head of suitable width for use with divers near the bottom (Figure 6-4).

Roe et al. ⁷⁴ reported on concurrent work at the Naval Civil Engineering Laboratory and stated that a polymer film overlay system would best achieve the goal of bottom stabilization. Bonding of adjacent strips was a desirable feature of this method. Flocculating agents and soil stabilization were also considered. Flocculating agents did not keep sediment from resuspending if disturbed and stabilization of soil required injections of large amounts of binding materials into the sediment in what was felt to be a semipermanent procedure. It should be noted, with reference to this study, that permanence is not necessarily desired in a bottom coating, as many spilled materials could be safely removed after initial control of the spill is obtained.

Roe et al. 74 indicated that pilot studies of a dispensing system were conducted in 50 ft of water. The system was essentially a pressurized hose and applicator composed of a slitted length of hose or tubing similar in shape to a wide vacuum cleaner nozzle. Design features for a chemical overlay system included 2000-sq ft/hr coverage



Reprinted from Marine Technology Society Journal (MTS) "The Application of a Polymer Film Formed Underwater," by M. Epstein and M. Widman by permission of MTS

FIGURE 6-4. TWO-PHASE IN SITU FILM DISPENSING HEAD.

and availability for depths up to 120 ft.

Extension of the polymer film cover concept to mercury pollution control was reported in the more recent work by Widman and Epstein. 47 In this report, the sodium alginate films were found to be highly biodegradable and, due to their high water content, were not considered to be good pollution barriers. It was from this work that the concept of using preformed commercially available films was formulated. Erosion-control capabilities of a polymer overlay could be useful in combined usage with, for example, a fine-grained soil sealant such as one of the bentonite-related materials.

Widman and Epstein ⁴⁷ report that the most effective film material was preformed nylon 6 (polycaprolactum), shown to be an effective barrier to both inorganic and organic mercury compounds. Other films tested (high-density polyethylene, low-density polyethylene, polyvinyl chloride, alcohol-soluble nylon, and poly (ethylene-vinyl acetate) copolymer hot melts) were equally satisfactory against inorganic mercury compounds. They varied in performance against organic mercury compounds, none being as effective as nylon 6.

Costs of the various systems (as reported in 1972) show that a preformed film overlay might be deployed for 1.5 to 3.3 cents per sq ft. Hot melt film might cost 2.5 cents per sq ft, while the coagulable nylon 6 might cost 4 cents per sq ft. Based largely on this cost advantage, preformed film was chosen for the bulk of the development work.

There is an indication that the preformed film overlay system would be deployable in water from 25 to 30 ft deep. ⁴⁷ Application rates indicated in cost calculations were 2 acres per hour under "favorable" conditions, making the system reasonably responsive to a spill, once it is on site. This would make it usable in most nonchannel areas of harbors and ports, as well as rivers. Nonnavigable water could not be traversed by the application equipment, while open waters would possibly be too deep for effective application. Difficulties with its use (vent holes to allow trapped gases to escape, weighting, and the possibility of puncturing) have been discussed to some degree in Chapter 5. The

materials are not expected to cause environmental problems, other than the obvious smothering effects on benthos.

There are several current candidates for use as covers. A number of polymeric liner materials (including some tested by Widman and Epstein) have been reported as being used for sanitary landfills, among them: polyethylene, polyvinyl chloride, butyl rubber, Dupont Hypalon (a synthetic rubber), ethylene propylene diene monomer, and chlorinated polyethylene. Polyethylene, the least expensive, has good chemical but poor puncture resistance. It might be used on smooth bottoms or as a temporary measure. Polyvinyl chloride is tolerant of a number of chemicals, but becomes stiff in cold weather. Butyl rubber is not recommended for cover of hydrocarbons and solvents, but is resistant to water-based inorganic salts, sewage, oxidizing chemicals, and animal and vegetable oils and fats. Hypalon suffers largely from high cost, but is also low in tensile strength. Ethylene propylene diene monomer (EPDM) is not recommended for solvents or hydrocarbons, but is resistant to mild concentrations of acids, caustics, and other chemicals. Chlorilorinated polyethylene has low resistance to chemicals, acids, and caustics and is not considered a good prospect.

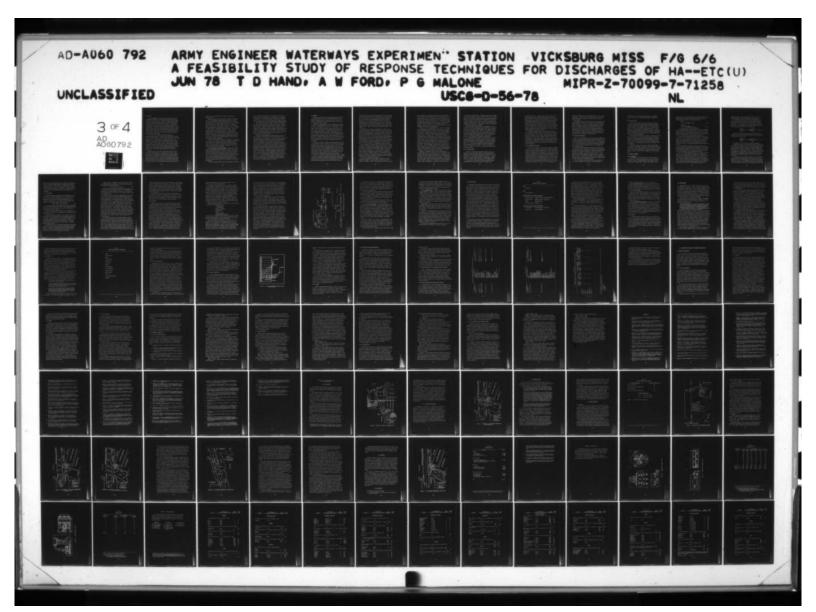
In summary, proposals for the use of polymer film overlays for cover of hazardous materials stemmed from early erosion control efforts related to marine salvage work. A barge-mounted concept of roller deployment for preformed films has been proposed, with an optimum deployment depth of 25 to 30 ft and an application rate of 2 acres per hour. Such a system could find application in rivers and ports and harbors. The roll system might be used in conjunction with a soil sealant cover to help control the erosion of unconsolidated fines inherent in the sealant application. Costs as high as \$0.03 to \$0.04 per square foot (1972 prices) were estimated. Impact on biota is not expected to be significant, other than the obvious smothering of those benthic flora and fauna in the application area which may have survived the effects of the toxic spill. Such covers should be considered of moderate potential, due primarily to the capital equipment required to place them.

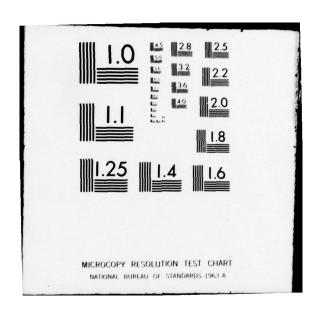
6.4.4 Gels

6.4.4.1 Background. Gels (other than the polymer film covers mentioned in the previous section) have been proposed for use on land and surface water spills, but no literature has been uncovered related to spills of hazardous chemicals that sink. Ziegler and Lafornara reported on the use of gelling agents on land spills. Polymer-based, water-soluble gels were placed on soil to prevent penetration of the spilled material. Density and water solubility were keys to the success of this method. Substances less dense than water and insoluble or only slightly soluble in water "may be prevented" from entering the soil. Further, substances miscible in water could be retarded by thick layers of gelled water. Heavier than water substances that were insoluble would pass through the barrier.

Pilie et al. have combined four powdered polymers into a universal gelling agent. Each polymer was effective against a certain class of hazardous chemicals: aqueous liquid, low-polarity inert spirits-type liquid (e.g., cyclohexane), polar organics, and alcohol. The feeling was that a universal agent could be applied with similar effectiveness to a wide range of spills. Initial application was intended to be on land or on the surface of water to reduce spreading or improve entrapment and rehandling of the spilled liquid. Reactions including polymers were noted to be exothermic, and explosion hazards are possible, depending on the concentration of polymer and spilled substances. Catalysts used in the polymerization process could also be harmful to aquatic life.

Field tests were conducted with various blends of gelling agents. Commercially available devices, including shovels, hand-pump dusters, dry chemical fire extinguishers, and sandblasters were used to disperse the gelling agent. On water, it was noted that some gelled materials would sink after a period of time and that bioassays revealed that fish ingesting the material died. It was noted that personnel handling these materials should be protected against skin contact with and inhalation of the gelling material. After entrapment of the spilled material by the





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gelling agent, the hazardous chemical could be easily removed by mechanical means.

Further optimization of gelling agents was reported by Michalovic et al. 46 Several blends of different gelling agents were tested for effectiveness on selected spilled materials and for costs. The blend chosen was a mixture of 5 percent Dupont Gelgard, 30 percent Dow Imbiber Beads, 30 percent B. F. Goodrich Hycar, 25 percent B. F. Goodrich Carbopol, and 10 percent Cabot Corporation Cabosil. Costs (including mixing and packaging) of the material were reported at \$2.00 to \$2.50/lb in 1,000-lb batches. Prices were based on 1975 levels. Costs of the covering operation itself would be additional. Material form was optimized as well. The powder gave way to a "roll-compressed" and chipped form that was not severely affected by wind and tended to sink below the water surface slowly, rather than reacting on the surface of the water. Dry chemical fire extinguishers, sandblasters, snowblowers, and a pneumatic conveyor were tested for application. Only the snowblower was removed from consideration.

A number of gelling agents have also been suggested for application to the control of oil spillage. Possible gelling agents, as reported, 76 include molten wax or soap solutions, lanolin, liquid solutions of natural fatty acids, soaps of the alkaline metals, treated colloidal silicas, amine isocyanates, and polymers. Technology for these agents is not well developed at the present time.

6.4.4.2 Application to Sinking Chemicals. Application of gelling agents to sinking chemicals has not been made. However, the previous background information provides a framework for possible development of methods for gel deployment in the case of sinkers. The work by Pilie et al. and Michalovic et al. indicates that multipurpose gelling agents, if they could be successfully placed on the bottom in the event of a sinker spill, might be effective in controlling the spill. A number of the liquid chemicals presently under consideration could conceivably be gelled by one or more of the components of the universal gelling agent.

A pressurized delivery system, with a broad dispersion head similar

to that considered for application of sodium alginate films, ⁷² could possibly be used for dispersion of the gelling agent. By bringing the gelling agent into close contact with the spilled liquid, it might be possible to gel it in situ, thus preventing further spread of the material and promoting early recovery using conventional dredging equipment.

The major problem with such a method is finding a gelling agent with sufficient specific gravity to remain on the bottom. It might be necessary to mix the agent with a carrier material to ensure successful bottom placement. Epstein and Widman considered several carrier materials in their polymer film work, including titanium dioxide, barium sulfate, iron powder, Georgia kaolin, and others. Further, impacts on benthic and pelagic biota would have to be studied in order to determine whether or not the gelling agent would result in more harm to the environment than the spilled chemical.

Application of gelling agents is probably feasible in water up to 120 ft in depth. This is based on some of the predictions for performance mentioned in the literature. Some form of pressurized delivery system would be needed. Strong currents will present some problems, though no documentation was found to indicate the significance of currents on the technique. Gelling agents are probably applicable in all of the scenarios in this study with the exception of areas with very strong currents. The gelled material could perhaps be recovered using conventional dredging techniques, although this would be dependent on postdeployment properties of the material, which are in most cases not determined at this time. The greatest potential for gelling agents lies in their use as temporary minigation techniques for hazardous liquid spills. Several different types of gelling agents might be needed to cover the range of different liquid chemicals in this study which would increase the cost of this technique. Extensive development work is needed on the applicability of gelling agents to hazardous chemicals that sink. For these reasons, only a low rating can be assigned to gelling agents as a response technique at this time.

6.5 SORBENTS

Sorption processes have long been considered among the most promising treatment methods for spills of hazardous materials in water. Sorbents are frequently used in conjunction with the control of oil spills and certain of them, such as activated carbon, have also been used in water purification systems.

Sorbents, as a generic group, function by "soaking up" liquids or impurities. Sorbents designed for oil use will preferentially soak up oil; that is, the material is oleophilic, or oil attracting. A side benefit of such oleophilic materials is that they will also tend to attract other liquid organics as well, making them potentially useful for the sinking liquid organics. Examples of sorbents used for oil range from natural mineral products (e.g., sawdust, ground corncobs, etc.) to synthetics such as polyurethane and urea formaldehyde foams and polyethylene and polypropylene fibers. These sorbents vary in their efficiency, the organics retaining from three to six times their weight, while the synthetics can sorb from 20 to 25 times their weight in oil. The organic sorbents also soak up water, which contributes to their inefficiency.

Application of sorbents to spills of materials other than oil has been successful in the past. Shuckrow et al. 77 indicated that sorption processes would be useful for such spills because of the effectiveness of sorbents on a wide range of hazardous chemicals, as well as the ability of sorbents to "hold" the hazardous material for a significant length of time. Ziegler and Lafornara 42 reported on adsorption tests using activated carbon. Carbon adsorption was considered to be potentially effective in removing heavy metals from solutions, and among these, efficiency was greatest on lead and mercury compounds.

Bauer et al.⁴ have rated sorbents as the chemical agents of highest potential in the treatment of hazardous material spills, based primarily on range of application, availability, and feasibility of deployment. Activated carbon was considered the most advantageous sorbent. Polyurethane foam and polypropylene fibers and other sorbents followed.

Application of these sorbents to representatives of the various classes of sinking chemicals under study was also summarized. Activated carbon was found to have application to representative hazardous chemicals in each of the categories of sinking hazardous materials, while other sorbents, such as the proprietary Amberlite XAD-4 resins and olefin polymer fibers, were found most useful for the control of the sinking solid aldrin when it is dissolved or dispersed in water. Agents useful for amelioration of aldrin spills (the substance is now banned in this country) should be useful for spills of other hazardous materials in its category.

Application of sorbents poses some problems. Since most of the sorbents available were originally intended for use on oil spills, many of them float, making their use on the bottom impossible unless special delivery systems are designed. With regard to oil spills, sorbents are most useful in cleaning up small spills and spills in obstructed and difficult-to-reach areas. In the context of spills of sinking hazardous materials, the use of sorbents will likely be most efficient in non-navigable waters, difficult to reach port and harbor areas, and along or in close proximity to riverbanks. Application to confined spills would prevent problems with sorbents degrading nearby clean water and land areas. Use in open waters will be expensive and, perhaps, unwieldy.

Delivery systems for sorbents used on oil spills will provide some insight as to their application for sinking hazardous spills. Sorbents are available in boom form, being designed to contain the spill as well as to sorb it. Sorbents also come in floating pads of varying sizes easily reuseable by wringing out. Strips and "chips" of synthetic sorbents have been arranged into "pillow" form or can be applied directly to the spill. Organic sorbents (e.g., straw, ground corncobs, peat moss, and sawdust) are particulate in nature. These, plus chipped foam, may be blown into the surface of a spill using a device similar to a hayblower used in highway landscaping work.

The use of sorbents in pads, pillows, and booms in control of sinking spills appears to have some promise. Such devices could be weighted, if necessary, to permit their deployment on the bottom. Buoys could be attached to lines to mark them and to permit easy retrieval. Best use would occur in relatively shallow waters, where deployment and retrieval would be less of a problem, and accurate deployment to the location of the spill would be simplified. Use of a boom would have the added advantage of acting to confine the spill. Some difficulty might be expected in getting other than the outer layer of confined sorbents to perform effectively using the above arrangement, especially if powdered or fine granular forms are used. High surface area, low volume containment devices would prove advantageous.

Shuckrow et al. 77 have suggested injection of slurries of sorbents (e.g., activated carbon) below the surface of the water. It was noted that air-deployable slurry and injection units would be most valuable, as these could be transported to the site of a spill quickly enough to be of some use. Such units could be mounted on workboats used in combatting the spill. Activated carbon is available with densities sufficiently greater than water that a slurry made with it would remain on the bottom. Use of such mechanical injection methods would allow the activated carbon (or other sinking sorbent) to be used in medium as well as small spills and also in deeper and more open waters of ports and harbors. Due to dispersion problems, such a technique might not be successful in high current areas, where the sorbent could spread into virgin areas. Certain confinement techniques (e.g., submerged dikes, trenches or booms, or the hazardous material spill barrier) could be used in conjunction with such a method to aid in controlling dispersion. Removal of the sorbent slurry could be accomplished using a handheld vacuum pump, or in the case of larger spills, a dredge.

Suggs et al. ⁷⁸ suggested the use of coated cotton meshwork to remove inorganic mercury from contaminated water and sediments. Such a technique would appear to have direct application to the present study especially since many of the sinking chemicals (e.g., heavy metals and pesticides) will bind themselves strongly to sediments. A high surface area, sulfur-coated cotton mesh was successfully devised as a "getter" system for mercury. Suggs et al. ⁷⁸ reported that, of the possible mesh materials tested (including plastic and metallic materials as well),

cotton accepted coatings the best. Coating was accomplished by dipping the mesh into a solution of sulfur in volatile solvents. Such a process appears to have potential in sorbent application to sinking chemicals in the case of both small and medium spills. The meshwork net could have the added advantage of erosion control, preventing or lessening resuspension of spilled materials. The cotton net could be incinerated after retrieval from the spill site. The potential of the various sorbents as coating materials needs to be evaluated.

Another potential technique for sorbent deployment and recovery discussed in the literature is magnetized activated carbon, a technique presently being developed with EPA support for use on Kepone amelioration in the James River, Virginia. Details of this method and results of research are unavailable at the time of this writing. However, it has been reported that the method, which includes tilling the special carbon into sediments and subsequent removal, "shows promise." Results of the work should be available in the near future.

The following subsections present brief descriptions of selected high-potential sorbents including the results of research relating to general effectiveness, cost, and availability of the treating agents. Much of this discussion has been summarized from information found in Bauer et al. This has been supplemented through discussions with selected manufacturers of the sorbents. Sorbents to be discussed include: activated carbon, polymeric sorbents, macroreticular resins, and molecular sieves.

6.5.1 Activated Carbon

Bauer et al. 4 suggests that activated carbon may be useful in absorbing virtually all sinking chemicals, the exceptions being the sinking solids barium carbonate, lead arsenate, phosphorus, sulfur, and liquid mercury. (These have been discussed in Chapter 5.) Activated carbon has also been reported effective on a large number of other chemicals, including o-Cresol, chloroform, DDT, and toxaphene. 80,81

Activated carbon is available in a number of forms, including powdered, granular, rod, sheet, and others. Techniques under

consideration here (slurry or bagged application) use either the powdered or granular forms. Carbons of various densities (including heavier than water) and various sorption properties are also available, making the task of optimizing the use of activated carbon to the spill of a particular hazardous material difficult. Prices vary widely depending on the specific form of carbon used. Bauer et al. 4 reports prices vary from \$0.20 to \$2.50/lb (1975 prices). Recent discussions (1977) with manufacturers revealed the price of unspecified carbons (FOB plant) to be about \$0.23/lb in bulk truckload lots. Due to its widespread use throughout the country, common forms of activated carbon are usually available on 1-day notice or less.

In summary, activated carbon can best be applied to chemical spills in the form of booms, pillows, or other bags, or within confined or curtained off spill areas. Recovery will be enhanced if such procedures are followed. To be effective, application should surround, and/or blanket, the spill areas. Negative impacts of carbon on biota surviving a spill would stem from burial, if a slurry or blanket technique was used. Activated carbon also has the disadvantage of turning water black due to carbon fines. Overall, activated carbon must be rated as having a high potential as a sorbent for use in this type of response technique.

6.5.2 Polymer Foams and Fibers

A wide range of polymeric sorbents has been developed in conjunction with oil spill recovery work. Among these have been polyurethane foams and polyethylene and polypropylene fibers. These have been manufactured in a number of forms, including belts, pillows, pads, and roll blankets. The possibility of these materials being deployed for spills of sinking chemicals has been discussed earlier in this section. It is expected that, because of the oleophilic properties of these materials, they will likely find at least some applicability to spills of liquid organics as well as spills of selected organic solids. Bauer et al. 4 report that "no currently available polymeric sorbents can be viewed as more readily available, better tested, or better in performance or

potential for use against spills of hazardous chemicals on water than polyurethane." Other types of foams or fibers may work, though local availability will play a large part in their potential for use in a response technique.

Polyurethane foams have reportedly been formed on site which could prove advantageous. Their use is not considered to contaminate water, though it may pose a fire hazard to handlers. Bauer et al. 4 received quotes of from \$0.26 to \$1.74/lb for undifferentiated foam products. Many of these polymeric materials are available from oil spill contractors in ready to use form, and their availability through this network makes the transfer of material and technology to the control of hazardous materials a simpler task than it otherwise would be. As a result, polyurethane foams must be considered as having a moderate to high potential as an adsorbent in a spill response.

6.5.3 Macroreticular Resins

Bauer et al. 4 characterized macroreticular resins as "polymers with a spongy or reticulated structure that is a small-scale replication of the macroporous structure of polyurethane foam or a large-scale replication of the molecular porosity of activated carbon." It is interesting to note that such resins may easily be given ion-exchange characteristics, so that the distinction between sorbent and ion-exchange resin becomes somewhat unclear.

It was noted that these resins are capable of sorbing dissolved aldrin and phenol and are considered "more versatile" than polyurethane foam, but less so than activated carbon. The discussion indicated that they have not been used on a large scale, and thus there is little information on deployment techniques or impacts on biota. It is expected, however, that deployment techniques and likely use scenarios would be similar to those noted for activated carbon. Desorption would likely pose many of the same problems as it would with activated carbon, again due to the nature of the sorbed material.

Due to the present low-level use of such resin, availability on short notice is expected to be a problem. These resins should be considered for use on an "as available" basis only. The commercial source for such resins is the Rohm and Haas Company, Philadelphia, Pa.

6.5.4 Zeolite Sieves

Zeolites are traditionally used in water treatment, chiefly for softening. They sorb ions or molecules and can be made size specific. Once again, the distinction between sorbent and ion-exchange becomes difficult. Bauer et al. 4 recognized the value of a type 5A molecular sieve (5 \times 10 $^{-8}$ cm pore size) for the sorption of bromine. No other application to sinking hazardous chemicals was noted, and no application to actual hazardous material spills was noted in any case. Technology related to these zeolite sieves as they apply to sinking chemicals must therefore be considered undeveloped.

It was noted that zeolites have a tendency to sorb water as well as the intended chemicals, and desorption by water was also considered a drawback. Such sieves would have the highest potential in cases where they could be completely immersed in the sinking chemical basically limiting their use to immiscible liquids. Special deployment systems, not requiring or allowing prewetting, would have to be designed. None were suggested.

Such agents as zeolite sieves are not expected to be generally available, and will probably be expensive. Lack of technology available for deployment further reduces the practicality of their use. Use would have to be on an "as available" basis. In any event, their use would likely be confined to small spills in confined or other hard-to-reach areas.

6.6 CHEMICAL TREATMENT

6.6.1 Ion Exchange

Ion exchange is a process by which ions of a given species are displaced from an insoluble exchange material by ions of a different species in solution. The exchange material can be used on a once-through basis or regeneratively. The most common example of the ion

exchange process is cation exchange water softening in which calcium and magnesium ions in hard water are replaced by sodium ions from the exchange material according to the following equations:

Reaction:

$$RNa_2 + Ca^{+2} \longrightarrow RCa + 2Na^+$$
 (6-1)

Regeneration:

$$RCa + 2NaC1 \longrightarrow RNa_2 + CaCl_2$$
 (6-2)

where R represents the exchange material.

Ion exchange material can be classified into two types: inorganic mineral zeolites and synthetic organic resins. The zeolites find their principal use in water softening while the synthetic resins are used to exchange a multitude of ions in water pollution control, reclamation and recovery of precious metals, water softening, and catalysis.

Acids and bases can be neutralized to water when the anion (OH⁻) or the cation (H⁺) is absorbed by an exchange material. A corresponding amount of salt does not remain as would be the case with chemical neutralization. Strong and weak acidic and basic anion and cation exchangers and neutralizing resins are available and could be used in some cases for acidic or basic hazardous chemicals that sink (Tables 2-1 and 2-2).

Several different ion exchange resins have been used to remove carbolic oil (phenol) from wastewater and drinking water. There are ion exchange materials available for ionic, most polar, and soluble chemicals. Hazardous chemicals that sink, with their inherent low solubilities, could preclude the use of ion exchange in many cases.

Pilie et al. have investigated the use of ion exchange resins as a substitute for activated carbon in the amelioration of heavy metal spills in water. Activated carbon was shown not to be effective in the treatment of many heavy metals when they are not in an organic structure. A mixture of cationic and anionic resins used for the demineralization of water was used in the form of "tea bags." Ion exchange resins were shown to be much more effective than activated carbon in the removal of As⁺⁵, Cr⁺³, and Cr⁺⁶. Freely dispersed resins were more

effective than those in bags, though ease of removal of the resin following treatment was cited as a reason for using the bags.

Phenol removal by both cationic and anionic exchange resins was tested. Anionic exchange resin was found to be more effective on a percentage basis than activated carbon in removing phenol, though it took longer. A 10:1 exchange resin to pollutant ratio was used. The effectiveness of anion exchange for the removal of phenol from water is based on the ability of phenol to act as a weak acid:

$$OH + H_2O - O^- + H_3O^+$$
 (6-3)

Pilie et al.³ have pointed out that aniline could possibly be removed from solution by a cation exchange resin because of the ability of aniline to act as a weak base.

$$NH_2 + H_2 0 - NH_3^+ + OH^-$$
 (6-4)

No experiments were carried out to verify this hypothesis.

Given the wide range of ion exchange resins available and because each of them may be applicable to only a small range of hazardous chemicals, it might be worthwhile to develop a "universal exchange resin," patterned after the universal gelling agent. Several resins, anionic and cationic, could be combined to produce this agent. Delivery could be accomplished in a manner similar to that for activated carbon sorbent. Confinement of the exchanger in readily recoverable booms, pillows, mats, or similar devices would promote easy retrieval at some loss of efficiency.

Ion exchange resins are uniformly available on a nationwide basis, due in large part to the wide range of use in water purification and treatment. Pilie et al. quoted prices of \$0.34/lb for anion exchange resins and \$0.28/lb for cation exchange resins in 1975. Current prices (1977) vary from \$0.50 to over \$2/lb. This compares with \$0.24/lb for

granular activated carbon and \$0.08/1b for powdered activated carbon in 1975. On a cost and flexibility basis, ion exchange resins must be considered inferior to activated carbon. Development of a "universal exchange agent" might increase the flexibility of exchange resins, but would do nothing to improve the cost differential. Impaired efficiency in salt water would correspondingly reduce its usefulness in that environment.

6.6.2 Precipitants

Chemical precipitation occurs when two soluble compounds react in water to form an insoluble compound plus a salt. Precipitation of a species in solution can be brought about by the addition of a salt containing an anion capable of forming an insoluble compound (e.g., barium can be precipitated from a solution of barium chloride by the addition of a stoichiometric amount of sodium sulfate):

$$BaC1_2 + Na_2SO_4 \rightarrow BaSO_4 + 2NaC1$$
 (6-5)

In the case of a spill, the spilled chemical, after precipitation, would be in an environmentally inert form. The precipitate that settles out has the potential for removal from the bottom by dredging or the application of a suitable covering.

Care must be exercised in the selection of a suitable agent for precipitation. Overapplication or misapplication of a reagent can cause toxic side effects.

Chemical precipitation is generally a fast reaction, but the rate may be limited by the small solubilities of the hazardous chemicals in this study. It may be necessary to use containment procedures to allow the precipitating agent to remain in contact with the chemical spill long enough for the reaction to proceed to completion. In addition, mechanical mixing may be necessary to prevent a layer of precipitant from halting the reaction.

An examination of the list of hazardous chemicals that sink (Tables 2-1 and 2-2) reveals that only aluminum fluoride and barium carbonate spills are likely to be successfully treated by precipitation techniques. For the former, fluoride ions are toxic and for the latter barium ions are toxic and should be removed from solution.

Aluminum fluoride is somewhat soluble (0.559 g dissolve in 100 cc of cold water) and could be treated or covered with calcium carbonate. The following reaction would take place:

$$A1F_2 + CaCO_3 \rightarrow A1CO_3 + CaF_2 + (6-6)$$

Calcium fluoride is less soluble (0.002 g dissolve in 100 cc of cold water) and would precipitate from solution. The misapplication or overapplication of calcium carbonate could result in a pozzolanic reaction, forming a crust on the bottom. This could exert a toxic effect on pH-sensitive benthos.

In Chapter 5, the use of an active covering material that contains sulfate (e.g., calcium sulfate and ferric sulfate) was proposed for barium carbonate spills. It was also noted that seawater itself may contain enough sulfate to precipitate barium ions. Barium ions could be precipitated more rapidly in a contained spill situation by the addition of a sulfate salt (e.g., sodium sulfate) that is more soluble than calcium sulfate or ferric sulfate. Misapplication or overapplication of calcium sulfate could result in a pozzolanic-type reaction on the bottom, creating a crust. It should not cause any toxicity problems under aerobic conditions. Ferric sulfate is weakly acidic and could exert a toxic effect on pH-sensitive benthos. Under aerobic conditions, hydrated iron oxides may form and with their adsorptive properties may scavenge heavy metals from the water. They also may coat the gills of bottom-feeding fish. Sodium sulfate is soluble, but will not adversely effect the pH. It is relatively nontoxic, especially when used in a marine environment.

Technology for the delivery of precipitating agents is not well developed in a systems sense, though individual hardware components should be available. It seems likely that precipitating agents would be best applied in close proximity to the bottom, where they would intercept the toxic barium or fluoride ions prior to their entering the water column. Such an application could be achieved through the use of an active covering containing enough precipitating agents to react with the spilled chemical. This could be accomplished by pressure injection of a solution or slurry of the selected precipitating agent into the discharge

pipe of a dredge being used to place covering material. This would apply to medium or large size spills, primarily. In the event of small spills, and when containment has been achieved through the use of a hazardous material barrier or submerged dike, direct application of the slurry or solution could be accomplished with diminished chances for overapplication or misapplication of the covering material. Off-the-shelf hardware (pumps, hoses, and flow-regulating devices) is expected to be available for this application.

The costs associated with the precipitating agents discussed in this section are as follows: calcium sulfate costs \$100 per ton, ferric sulfate costs \$90 per ton, and sodium sulfate costs \$72 per ton. The above prices are for bulk quantities. Freight is additional and might cost from \$20 to \$60 per ton, depending on distance shipped.

6.6.3 Oxidants

Oxidation is defined as a reaction in which the valence number of an element becomes more positive. A substance that gains electrons from another substance, causing the latter to be oxidized, is called an oxidizing agent or oxidant. The complete oxidation of an organic substance results in the formation of carbon dioxide and water.

The most important agent for the oxidation of selected hazardous chemicals, oxygen, is commonly found in natural waters. The chemical and biological oxidation of hazardous chemicals on the bottom of a body of water will cause an increase in the oxygen demand resulting in a reduction in the concentration of available dissolved oxygen in overlying waters. To make this problem more acute, some lakes, rivers, and coastal waters already have critically low oxygen concentration levels because of high temperatures or because of industrial and municipal wastes.

Except in well-mixed or shallow water, oxygen is generally more abundant near the surface. The most important source of oxygen below the surface is photosynthesis. The rate of oxygen diffusion is extremely slow (20 ft per year in a sharp gradient). Chemical oxidation, therefore, may be greatly hampered due to depleted oxygen levels at the bottom. In addition, the toxicity of a spilled chemical may prevent

biological decomposition as well as remove the principal source of oxygen available for an oxidation reaction.

A previous study has considered the use of aeration techniques plus the addition of oxygen and ozone for the oxidation of selected hazardous chemicals contained in the water column. These oxidants were considered because they result in oxygenic reaction products only (i.e., CO₂, H₂O, and partially oxidized organics). The use of potassium permanganate, considered here, was not given serious attention because of the end products of the oxidation reaction (compounds of manganese) and because of the pollution hazard of unreacted permanganate. The oxidation products of permanganate, manganese oxide hydrates, are insoluble and as such would present no pollution hazard. The use of containment procedures (barriers, curtains, or submerged dikes) would allow more precise control of the oxidation reaction, thereby limiting the amount of unreacted permanganate released.

Hazardous chemicals that sink and are amenable to in situ oxidation are listed in the following tabulation:

2,4 Dinitroaniline
2,4 Dinitrophenol
Carbolic Oil (phenol)
Trichlorophenol
Cresols
Phthalic Anhydride
Diphenylmethanediisocyanate

In each case, the oxidizing agent must be brought into molecular contact with the hazardous chemical. This would require mixing of the system with the concurrent addition of the oxidizing agent.

There is available some technology for the introduction of oxidizing agents into the vicinity of a hazardous material spill. The addition of air and oxygen into the discharge stream of a hydraulic dredge has been accomplished in an effort to lower the Immediate Oxygen Demand (IOD) associated with the dredged material discharge process. The addition of oxygen into the discharge stream was accomplished through the vaporization of liquid oxygen (LOX), originally stored in

banks of pressure tanks. In another experiment, an air compressor was used to inject air directly into the discharge pipe. Measurements made during the oxygenation field demonstration showed that the direct injection of oxygen significantly reduced the depletion of dissolved oxygen in the disposal area. The aeration field demonstration was not conclusive in showing that the air injection mitigated dissolved oxygen (DO) depletion in the disposal area, though characteristics of the dredged material being tested may have colored this conclusion somewhat. A schematic of the oxygen injection system used on the experiments is presented in Figure 6-5.

It is difficult to determine the costs for a complete system at this time because the projected demand for oxygen on a ton per day or ton per hour basis is not known. As an example, however, a Pressure Swing Adsorption (PSA) system in which nitrogen is removed from the air by adsorption onto molecular sieves has a capital cost of approximately \$700,000 to produce 3 tons of oxygen per day and \$1.4 million to produce 9.8 tons of oxygen per day.

Also available are a number of devices used in the aeration of sewage lagoons and similar water treatment facilities. One system of particular note for the present case consists of an air blower or compressor device, a central manifold, and perhaps 16 radiating diffuser hoses, each consisting of a three-tube flexible, polymerized PVC hose. 83 The system is inexpensive, light, and, therefore, very portable. A manifold weighs 5 to 10 1b and costs about \$58. Tubing weighs about 1 lb/ft and is lead-ballasted. It costs about \$1.32 per foot. Thus a system containing 16, 25-ft hoses and 1 manifold would cost approximately \$586. To this must be added the cost of an air compressor (skid mounted for easy deployment) and enough flexible pipe of either 1- or 2-in. diameter to reach working depth. The air compressor must be sized according to depth and flow rate. The 16 hose, 25-ft diffuser indicated above would handle from 20 to 45 cu ft/min of air. At a 25-ft depth, in seawater, a pressure of approximately 12 psi would be required to operate the diffuser. This pressure would be doubled at a 50 ft depth.

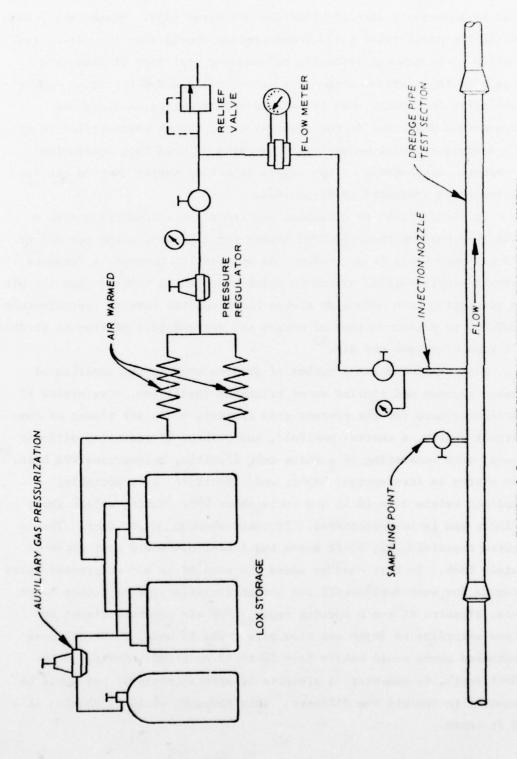


FIGURE 6-5. EXPERIMENTAL OXYGEN INJECTION SYSTEM.

The generation of ozone can be accomplished using equipment that operates with a feed stream of air or of pure oxygen. A stream of 1 to 6 percent ozone is produced from pure oxygen. Since ozone is more reactive than oxygen, it is possible that such a device might prove useful, despite this relatively low percentage. Ozone generators produce a product stream that is limited to 30 psig, which will limit the use of direct injection to shallow waters.

Potassium permanganate is highly soluble in water and will be best dispersed as a liquid. Pressure injection through a flexible hose to a submerged diffuser is possible. One diffuser concept would be similar to the aeration diffuser noted previously. An eductor with metering could be used to disperse a predetermined amount of permanganate solution into the diffuser stream.

Descriptions of selected potential oxidizing agents follow. Included in the discussion are indications of environmental impacts, plus any other noteworthy problems with the use of the material.

6.6.3.1 Potassium Permanganate. Potassium permanganate has been used advantageously for the removal of objectionable chemicals from wastewater, process solutions, and contaminanted air streams. Some organic compounds are completely oxidized by permanganate while others are partially degraded into simpler organics. Among the compounds destroyed by permanganate are aldehydes, phenols, olefins, and alcohols. Potassium permanganate will not oxidize saturated hydrocarbons. A ratio of 7:1 potassium permanganate to phenol (carbolic oil) requires 1 hr for the reaction to proceed to 90 percent completion. The products of oxidation are carbon dioxide, potassium hydroxide, and manganese dioxide.

Because of its purple color, control of the permanganate concentration and the oxidation reaction can be accomplished visually. As the permanganate reacts, its purple color changes to a yellow and then to brown, indicating that the oxidation is taking place. Overapplication and misapplication would have to be avoided as permanganate is a toxic chemical in high concentrations.

Only one chemical firm in the United States, Carus Chemical Company

of La Salle, Illinois, markets potassium permanganate and this is in conjunction with the wastewater treatment industry. Costs of potassium permanganate are \$1650 per ton plus freight, making it very expensive on a bulk basis. Due to this fact, it might best be used on an "as available" basis, particularly in light of the ready availability and/or portability of selected diffuser systems.

6.6.3.2 Oxygen/Aeration. Aeration can be an effective technique for the introduction of oxygen into water. Because molecular diffusion of oxygen occurs at a low rate, an effective aerator must continually change large surface areas through which the interchange may take place.

Aeration can be utilized for the oxidation of carbolic oil (phenol) in particular spill situations. ⁴ The reaction is slow (1 to 6 hr), and the use of containment procedures is necessary for effective oxidation. In shallow water, exposure to sunlight may enhance aeration oxidation of carbolic acid. Carbon acts as a catalyst and reduces the sparging requirements considerably. ⁴

6.6.3.3 Ozone. Ozone (0₃) is more reactive than oxygen and yields no by-products of oxidation other than carbon dioxide, water, and partially oxidized organics. Ozone has been shown in laboratory studies to reduce carbolic oil concentrations in the range of 2 to 7 ppm by more than 90 percent.

Commercial ozone generating equipment is available that operates on a feed stream of air or pure oxygen. At optimum efficiency and operating on pure oxygen, this equipment can deliver a stream that is from 1 to about 6 percent ozone. Ozone generators, however, produce a stream that is limited to pressures no greater than 30 psi. This would seriously limit compatibility with injection systems that would require pressures of 100 psi or greater. Ozone is not stable at elevated pressures or temperatures and would decompose to oxygen if a booster compressor were added to the system.

Since ozone has a significant inhalation toxicity, special precautions would have to be taken if it is used in a response.

6.6.4 Neutralization

Neutralization is the interaction of an acid with a base resulting in the formation of water plus a salt (e.g., $HC1 + NaOH \rightarrow H_2O + NaC1$). Excess acidity or alkalinity produced by some hazardous chemicals that sink are harmful to the environment regardless of the specific nature of the chemical. Treatment of the spill with a weak acid or base serves the purpose of returning the solution to a near-neutral pH without a large overshoot (in pH) if misapplied or overapplied. Hazardous chemicals that sink that are acidic or basic in nature or that react in aqueous solution to form an acid or a base are listed in Table 6-1.

The use of neutralizing agents for the amelioration of hazardous chemicals in the water column has been considered in detail by Drake et al. 5 The effective application of a neutralizing agent in the water column is difficult because dissolution and dilution of highly soluble spilled acids and bases are rapid. A sinking hazardous chemical, however, would mix with water to form a suspension with a density greater than 1.0. This suspension would spread laterally on the bottom due to gravitional forces. The process of eventual uniform distribution and dilution would be slow, requiring days for completion. In shallow and quiescent waters, the early part of spill amelioration could involve a containment procedure, such as the hazardous chemical barriers discussed previously. Use of such a barrier would allow for the effective application of a neutralizing agent followed by dredging or covering of the neutralized material. Application within the confined area would reduce the danger of damage to the environment from an excess of neutralizing agent.

The literature yields four primary candidates for neutralization of the chemicals related in Table 6-1. Neutralization of acidic materials can be achieved by calcium carbonate, sodium carbonate, and sodium bicarbonate. Sodium dihydrogen phosphate has been suggested for use on bases. Description of these chemicals is provided later in this report. Information is included on price, availability, and problems inherent in their use.

Table 6-1 Candidates for Neutralization

Acids

Benzoic Acid

Bases

Calcium Hydroxide

Chemicals that React in Water to Give Acids

Aluminum Chloride Hydrogen Chloride + (Aluminum Hydroxide)

Benzoyl Chloride Hydrogen Chloride + Benzoic Acid

Bromine Hypobromous Acid

Phthalic Anhydride Phthalic Acid

Chemicals that React in Water to Give Bases

Calcium Carbide Calcium Hydroxide + (Acetylene)

Calcium Oxide Calcium Hydroxide

Application can be accomplished in either olid or slurry form (powdered or fine grained) or as a solution. I number of techniques can be used for application of a solid, including hand shoveling, broadcast spreading, dumping from aircraft, or similar methods. Injection into a slurry of inert cover material could be used to form a cover that both retards leaching and neutralizes. A solution could be injected in the same manner or could be pumped directly to the bottom using an eductor with metering or direct pumping, for example. This material could be applied either in open waters or quiescent or confined spill locations in nonnavigable waters, rivers, ports, and harbors. A monitoring device (remote pH meter) could be used to locate pH imbalances and follow the neutralization reaction.

6.6.4.1 Calcium Carbonate. Calcium carbonate neutralizes acids by reaction with hydrogen ions to form carbon dioxide and water. The overapplication of a solution of calcium carbonate could result in a pH of up to 9.4. This is close to the pH range (6 to 9) of natural waters.

In neutralizing hypobromous acid, formed from bromine spills, the carbonate ions act to form soluble bromide ions. Bromide is a natural constituent of seawater and has a low toxicity when compared to bromine. In neutralizing benzoic acid and phthalic acid with calcium carbonate, calcium benzoate and calcium phthalate are formed. Both compounds are slightly soluble and eventually will be taken into solution. The toxicity of the benzoate and phthalate anions may still present a problem. Neutralization should be followed by some other chemical reaction or by physical removal (i.e., dredging) of the precipitate.

Calcium carbonate neutralizer can be made from limestone or marble. Bauer et al. 4 found that the more finely ground the material, the faster the neutralization reaction. Several companies supply 325-plus mesh calcium carbonate in bulk quantities at \$19 to \$20 per ton.

6.6.4.2 Sodium Carbonate. Sodium carbonate (soda ash) neutralizes acid spills in the same way as calcium carbonate. The overaddition of sodium carbonate, however, can result in a pH of 12 or higher. Sodium carbonate is available at \$42 to \$56 per ton in bulk quantities.

Application is suggested by Drake et al. at a 1-M solution.

6.6.4.3 Sodium Bicarbonate. Like calcium carbonate, sodium bicarbonate neutralizes acids by forming carbon dioxide and water. Misapplication of sodium bicarbonate could result in a pH of up to 8.3. The sodium salts of benzoic acid and phthalic acid are very soluble and the use of sodium bicarbonate as a neutralizing agent for these chemicals would preclude dredging.

Unlike the preceding neutralizing agents, which are bases for the neutralization of acids, sodium bicarbonate can also neutralize bases by forming carbonate ions. In the neutralization of calcium hydroxide, calcium carbonate would be precipitated. Drake et al. found sodium bicarbonate unacceptable for base neutralization because of the large quantity required. Sodium bicarbonate is available at \$50 to \$366 per ton in bulk quantities.

6.6.4.4 Sodium Dihydrogen Phosphate. Drake et al. found sodium dihydrogen phosphate to be the best choice for the neutralization of bases. Stronger acids were found to be unacceptable because excess neutralizing agent would cause extreme changes in pH. The misapplication of sodium dihydrogen phosphate could result in a pH as low as 4.5. In the neutralization of calcium hydroxide, calcium phosphate would precipitate. This compound is insoluble and would exert no toxic effect on the environment. The cost of sodium dihydrogen phosphate has been quoted at \$25 per ton in bulk quantities.

6.6.5 Results

The different chemical techniques discussed in this section may prove to be very useful in control of sinking hazardous chemical spills. Many of the techniques suffer from being chemical specific. Most of the techniques have not been tested in the field. These techniques appear to have a high potential as intermediate response techniques which would then be followed by dredging or burial. A great deal of development work is needed on most of the techniques as applied to hazardous chemicals that sink.

6.7 BIODEGRADATION

Biodegradation is not at this time considered a high potential spill amelioration technique. Further, it does not have great potential as an emergency response measure. However, there are compounds, especially organics, which, over time, can be biologically degraded, either by natural or artificially induced means, and precedents for biodegradation of hazardous materials spills exist. In the petroleum industry, for example, chemical dispersants will break up a slick of spilled oil into tiny droplets which are then dispersed through the water column in a form more susceptible to biological decomposition.

Significant work on the application of biological countermeasures to hazardous material spills has been done by Armstrong et al. 85,86 The Armstrong references recognize the opinions of Dawson et al. 87 which were stated as follows:

Biological degradation, while attractive in some respects, suffers from several difficulties. In order for degradation to proceed at a rapid rate, it would be necessary to have on hand large quantities of acclimated cultures. The problems associated with stockpiling many such cultures, each of which is specific to a particular substance, are obvious. Also, many hazardous materials are apparently resistant to biological degradation.

Armstrong, 85 however, points out that there is a body of literature and experience from the wastewater treatment field which tends to indicate that biological countermeasures may be effective against a wide range of hazardous chemicals. It is suggested that bacteria cultures stored in a dormant state (in either a frozen or powdered form) could be deployed easily and rapidly without highly specialized equipment. In situ deployment by spraying from a helicopter, shore, or boat was suggested. In addition to stored cultures, activated sludge wastewater treatment plants near the location of a spill might yield suitable cultures. Industrial wastewater treatment plants at the site of manufacture of certain hazardous materials (no specifics listed) could quickly provide cultures acclimated to the spilled material.

The investigation by Armstrong et al. 85 centered on a list of 14 of the 20 most hazardous chemicals listed by the EPA. Included on the

list were aldrin and DDT, both of which are under consideration in this report. Both were reported as biodegradable, ⁸⁶ but no active analysis of them was conducted, other than initial screening tests. The kinetics of biodegradation reactions on such persistent pesticides are likely to be very unfavorable.

Tests reported on phenol⁸⁶ have yielded some noteworthy results. Temperature is an important variable in biodegradation. It was noted that decreased metabolic rates at low temperatures could seriously affect biodegradation. Further, freshwater bacteria cultures might possibly not be useful in marine and coastal waters, as high salinities in water reduce the effective pH range where biodegradation might occur. A temporary dissolved oxygen impact will occur upon application of the countermeasure, though aeration might help reduce this effect.

Pond tests conducted on phenol⁸⁶ revealed the possibility of indigenous bacteria assisting in decomposition. Further, these same tests suggested in situ applications of both bacteria acclimated to the hazardous material and unacclimated bacteria (taken from a nearby wastewater treatment plant) would be effective in biodegradation. Nutrients (e.g., nitrogen and phosphorus) added to the treatment area will increase the rate of biodegradation which occurs.

Armstrong 88 notes that fairly quiescent areas will be required for any biodegradation to take place, and the spill must be contained. As to applicability to materials that sink, Armstrong notes that some bacteria cultures exist which will tend to sink to the bottom themselves, or they could be placed in sinkable bags. If cultures from sewage treatment plants were used in biodegradation, it is possible that pathogenic bacteria could be introduced into the waterway, and this could pose a problem greater than that of the hazardous material itself.

In summary, biodegradation cannot be considered a high-potential response technique at this time, though work is currently being done to refine the techniques. Limited to contained spills of organic materials in quiescent waters (drainage ditches, coves, and certain river, port, and harbor areas), the technique is plagued by problems of acclimation of bacteria cultures to specific hazardous materials, difficulties

in storage and handling, and uncertainities regarding BOD levels and the introduction of unwanted pathogenic bacteria. Recognition of these difficulties is inherent in Annex X of the National Oil and Hazardous Substances Pollution Contingency Plan (40 CFR 1510) which requires EPA approval prior to the use of any biological agents.

6.8 DISPERSION

Dispersion, whether by chemical or mechanical means, should not be considered as a first choice response to any hazardous material spill. Indeed, containment, rather than dispersion, should first be considered when a spill occurs. The U. S. Coast Guard CHRIS manual, while recognizing the use of dispersion techniques, suggests using such only sparingly, and even then only when all other corrective methods have been eliminated from consideration. Table 6-2 presents a list of those hazardous chemicals in CHRIS which have been suggested as possible candidates for dispersion in selected instances.

The principle behind dispersion is to spread out the spilled chemical so that the concentration of the material is reduced to below recommended limits within a relatively short transport distance from the spill site. Failure to do this would result in spreading the effects of the spill over a wider area. In some instances, for example organic liquids, this might permit increased biodegradation of the material. Typical instances where dispersion could be used are as follows:

- o In open water, where rapid dilution of the spilled chemical might be expected upon dispersion.
- In small streams flowing into larger rivers. In this instance, a spill dispersed in the stream would be carried to a nearby river where, presumably, the greater flow would result in quick dilution below recommended limits.
- o At the mouth of a harbor with fast tidal currents. These currents could make techniques such as covering difficult. Dispersants could be applied to the spill on an outgoing tide, whereupon the chemical would be carried to open water and diluted below recommended limits.

The use of dispersants must be subject to decisions made on a caseby-case basis. This decision would depend on environmental conditions

Table 6-2
CHRIS Chemicals Subject to Dispersion

Aniline

Benzoyl Chloride

Bromine

Calcium Carbide

Calcium Oxide

Carbolic Oil

Cresols

Dichloromethane

2,4 Dichlorophenol

Dimethyl Sulfate

Epichlorohydrin

Furfura1

Lithium Aluminum Hydride

Toxaphene

at the site, the amount of chemical spilled, the chemical's toxicity, and similar considerations.

Both chemical and mechanical means of dispersion are available. Technology for application of these to spills of sinking chemicals is not well developed, the greatest amount of experience coming from the control of surface spills. Chemical dispersants, for example, are available for spills of hydrocarbons and have been used on a number of spills. A discussion of the different types of dispersion mechanisms follows.

6.8.1 Mechanical Dispersion

Depending on the size and location of a spill, a number of mechanical dispersion devices are readily available. These can be deployed with only small capital hardware outlays. Water streams, from a fire hose connection on either ship or shore, could be effective in relatively shallow waters and for small spills. Propwash from a boat could also be used. Depending on the depth of water and size of spill, anything from an outboard motor to the wash of a tugboat could be used. The use of compressed air, perhaps in conjunction with easily deployable and commercially available lagoon aeration systems (such as the Schramm "Aqua Puss" Lagoon aeration system), 83 could be used to disperse selected materials from the bottom. The Aqua Puss system consists of a central manifold surrounded by radiating diffuser arms, consisting of three-tube poly rized PVC hose. Air is supplied by a surface compressor. As air rises in the water column, bottom water is entrained and pushed toward the water surface. This would allow currents in the water column to carry away the spill. It is possible that this could be used in conjunction with propwash or water-jet dispersion to effect more complete dispersion. It is also possible that a temporary system similar to the above could be made from readily available PVC hose and a gasoline-driven compressor. This setup was suggested in CHRIS for use in air barriers.

Procedures for use of propwash, water jets, and compressed air in oil spills are usually associated with movement of a slick from obstructed

areas and towards skimmers (this is not dispersion, but uses many of the same techniques). Booms could be used in conjunction with such methods to assist in deflection of oil towards a desired location. It is equally likely that the hazardous material spill barrier could be used in a similar mode for the deflection of sunken spills. This might enable the spill to be cleared from obstructed areas in a manner similar to oil. Both solids and liquids could be moved in this manner, though the procedure would work best with liquids due to their flow characteristics. A diagram detailing the combined use of a water jet and boom for oil in a pier area is shown in Figure 6-6.

An additional means of mechanical dispersion, probably useful in small streams flowing into larger rivers, consists of flow augmentation using water stored upstream of a spill. This could be released to wash the spill into the river. This method, suggested by Dawson et al., 87 would be partially dependent on the availability of a means of predicting duration of toxic concentrations, flow rates, etc., for the water body. These may not always be available.

6.8.2 Chemical Dispersion

Chemical dispersion methods have not been developed for use on spills of sinking hazardous materials. However, a number of dispersants are available for use on oil spills. These dispersants are molecules with an oil soluble (lipophilic) end and a water soluble (hydrophilic) end. The dispersant will locate and orient itself at an oil-water interface, reducing surface tension and permitting dispersion into the upper portion of the water column of fine droplets of oil.

Application of such dispersants has been accomplished using handoperated pumps and pressure units, portable pump eductor systems,
specially prepared vessels with attached spray booms, and helicopters or
other aerial spray methods. Mixing, possibly using the propwash of a
surface workboat, may be necessary to aid in dispersion, though self-mix
dispersants are available. It should be noted that these dispersants
are less dense than water and, in their present form, would not be
useful for bottom spills. Chemically speaking, however, they could be

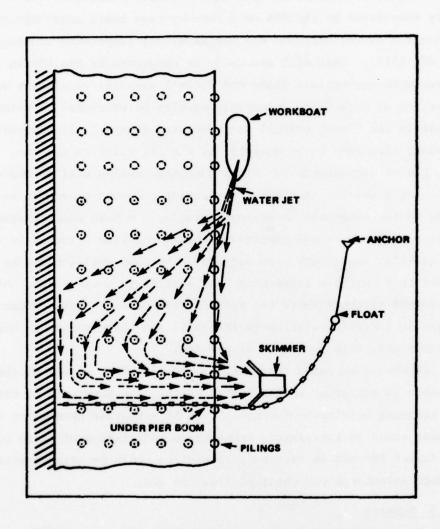


FIGURE 6-6. CLEARING OIL FROM UNDER PIERS WITH BOOM AND WATER JETS.

expected to apply generally to the liquid organic materials of present concern.

Any application of dispersants to spills of sinking liquid organics would likely be limited to open-water areas. Dispersant use is presently considered by the EPA on a case-by-case basis under the authority of Annex X of the National Oil and Hazardous Substances Contingency Plan (40 CFR 1510). This will generally be conducted by the EPA in consultation with appropriate State and Federal agencies consistent with reduction of hazards to vulnerable species of waterfowl or which will result in the "least overall environmental damage." In any case, dispersants will have to be accepted by the EPA prior to any use.

Use of dispersants for sinking organic spills will depend on formulation of a heavier than water surfactant compound proven to be applicable to the chemicals under consideration. A pump eductor system using a water pickup hose and dispersant metering device attached to drums of the material might serve the purpose. The pump outlet could be connected to a suitable dispersing head similar to a spray bar, this being positioned slightly above the spill at the ocean bottom. Water volume should be large in relation to the spill and there should be high currents available to aid in dispersion.

It should be noted that, at the present time, supply of the dispersants is not great in the United States, due primarily to difficulty in obtaining permission for use. Even if a heavier than water dispersant could be formulated, manufacture and storage of it in quantities sufficient for use in emergency situations would be delayed until product acceptance was obtained from the EPA.

6.8.3 Summary

Dispersion should generally be avoided in most spill situations and used only as a last resort. The only large-scale field testing of dispersion techniques has been in the area of oil spills. No dispersant formulation for chemicals that sink is presently available. As a result, a low rating must be assigned to dispersion as a response technique in this study.

6.9 OTHER RESPONSE TECHNIQUES EVALUATION

The techniques discussed in this chapter are considered to have some potential for responding to spills of hazardous chemicals that sink. Many of these techniques are untested and require development and are somewhat chemical specific. The greatest potential for many of the techniques is as a temporary or intermediate step in an overall response program.

Containment devices have a high potential for containing the spilled chemical and for containing unconsolidated treatment materials. Curtain barriers require more development, are expensive, and will probably be limited to quiescent water. Dikes are easy to construct, but require significant construction time. They are not practical in heavily used water because they obstruct navigation. Trenches could be very successful in containing spills that move along the bottom of a waterway. They are cheap and easy to construct with a relatively fast response time.

The cover materials discussed in this chapter have potential in both temporary and long-term response techniques. Grouts and cements are easily obtained, but require significant time to place. They are also difficult to remove with regard to conventional dredging equipment. Soil sealants are, for the most part, untested. They are also expensive and would probably tend to erode. Polymer covers show some potential, but require additional development. They are fairly expensive and require special equipment for deployment. Gelling agents have not been developed that can be applied to sinking hazardous chemicals. The development of a universal gelling agent would provide a needed temporary response technique with a short response time.

The sorbents included in this chapter can be used in intermediate response techniques followed by dredging or burial. Activated carbon is a good adsorber of many of the organic chemicals, but development of a technique for deployment is needed. The other sorbents (polymeric, macroreticular resins, and zeolite sieves) are fairly chemical specific, untested in sinking chemical spills, and also require development of a

deployment technique.

The chemical techniques discussed in this chapter (ion exchange resins, precipitants, oxidants, and neutralizers) are mostly chemical specific. They are mostly untested in sinking chemical spills; some are relatively expensive; and some, like the sorbent techniques, require development of a deployment method.

Biodegradation has a low potential as a direct response technique. This technique is limited by availability of acclimated organisms and severe deployment problems.

Dispersion is not usually an environmentally or socially acceptable response technique, but in some situations it may be the best solution to the chemical spill problems. Techniques for mechanical dispersion are readily available in most areas. Techniques for chemical dispersion suffer from the unavailability of dispersant formulations that sink.

6.9.1 Responses Appropriate to Functional Classes of Chemicals

In order to summarize the applicability of the response techniques in this chapter to the chemicals under study, Table 6-3 has been prepared. The chemicals have been grouped according to similar characteristics. The recommended responses presented in this chapter are given for each group of chemicals. It should be noted that many of these techniques are untested and are presented only as potential responses. This table should be used along with Table 6-4 (Responses, Other Than Dredging, Appropriate to Various Spill Scenarios) in choosing a response technique.

6.9.2 Responses Appropriate to Various Spill Scenarios

The appropriateness of the response techniques discussed in this chapter as applied to the various spill scenarios is summarized in Table 6-4. It was deemed inappropriate to apply a numerical ranking to the response techniques at this time since no field application information is available on many of the techniques. Therefore, a rating as to potential for success is given in terms of low or none, moderate, or high. These ratings are based on information presented in the chapter

Table 6-3 Responses Other Than Dredging Appropriate to Functional Classes of Chemicals

Characteristics	Chemicals Represented	Recommended Responses
Solid; inorganic; reactive with water	Aluminum Chloride Calcium Carbide Calcium Oxide Lithium Aluminum Hydride	Containment; temporary cover; chemical treatment by neutralization
Solid; inorganic; reactive with air	Red Phosphorus White Phosphorus	Request special handling by manufacturer; oxidation in situ
Solid; inorganic; relatively insoluble and nonreactive in water	Aluminum Fluoride Barium Carbonate Calcium Fluoride Calcium Hydroxide Lead Arsenate Sulfur (after cooling)	Covering; neutralization; precipitation of toxic ions
Solid; halogenated organic	Aldrin Benzene Hexachloride DDT p-Dichlorobenzene 2,4-Dichlorophenol Pentachlorophenol Toxaphene Trichlorophenol	Containment; covering (mostly temporary); adsorption
Solid; nonhalogenated organic	Asphalts Benzoic Acid Bisphenol A Carbaryl Dibenzoyl Peroxide 2,4-Dinitroaniline 2,4-Dinitrophenol Diphenylmethane Difsocyanate Naphthalene Phthalic Anhydride	Containment; covering (mostly temporary); adsorption

(Continued)

Table 6-3 (Concluded)

Characteristics	Chemicals Represented	Recommended Responses
Liquid; inorganic	Bromine Mercury	Containment; neutralization; adsorption
Liquid; halogenated organic	Benzoyl Chloride Carbon Tetrachloride Chlorobenzene Chloroform o-Dichloromethane Dichloropropane Dichloropropane Dichloropropane Epichlorohydrin Ethylene Dichloride Ethylene Dichloride Trichloroethylene Trichloroethylene Trichloroethane Trichloroethane Vinylidene Chloride	Containment; adsorption; oxidation; biodegradation
Liquid; nonhalogenated organic	Acetophenone Aniline Benzaldehyde Cambor Oil Carbolic Oil Carbolic Oil Carbolic Oil Carton Bisulfide Cresols Dibutyl Phthalate Dibutyl Phthalate Dowtherm Furfural Glycidyl Methacrylate Malathion Methyl Parathion Methyl Parathion Containing Lead Alkyls Nirrobenzene Tetraethyl Lead Tricresyl Phosphate	Containment; adsorption; oxidation; biodegradation

Table 6-4 Responses, Other Than Dredging, Appropriate to Various Spill Scenarios

				Ports and Harbors	Harbors	Open Waters	laters
	Land and	Riv	Rivers	In	Outside	High Current, Neither High	Neither High
	Nonnavigable Waters	High	Low	Navigation Channels	Navigation Channels	Great Depth, or Both	Current Nor Great Depth
Containment	ж	M	Н	×	н	1	×
Covering	ш	M	×	I	×	1	×
Sorbents	М	Г	×	M	×	T	M
Chemical	M	1	×	×	X	M	×
Biodegradation	1	T	1	ı	1	ı	ı
Dispersion	1	E	1	×	Г	M	×

Note: Potential as a response technique:

L = Low or none

M = Moderate

H = High

as found in the literature. The ratings cover use of the technique as both temporary and permanent responses to a spill.

A number of factors were considered in developing the ratings, including compatability of the technique with the environmental setting, availability of necessary supplies and equipment, and overall efficiency of the technique in terms of response time and costs. Many of these factors were estimates since little information from actual field use of the techniques was available.

It must be emphasized that since many of the techniques are both chemical and scenario specific, the final choice of a technique must be based on actual conditions at the spill site. Tables 6-3 and 6-4 should be used only as an aid in determining the most appropriate response technique for a particular hazardous sinking chemical spill.

7.0 SUMMARY AND CONCLUSIONS AND RECOMMENDED RESEARCH PLAN

7.1 SUMMARY AND CONCLUSIONS

Very few firm conclusions can be drawn concerning the subjects covered in this report, as there has been little work accomplished that directly relates to spills of the 70 chemicals under study or to the various proposed response techniques. Thus, any conclusions are necessarily tentative and based on induction, extrapolation of related data, and engineering judgment. Extensive research and development are needed in all the task areas to establish a truly objective basis for response decisions. Nevertheless, the following paragraphs summarize the key findings and restate tentative conclusions generated in the previous chapters.

7.1.1 General and Chemicals

With few exceptions, the 70 chemicals under study constitute a severe hazard if discharged into any of the various environmental settings—the greater the quantity discharged, the greater the potential damage to human and/or aquatic and benthic populations. For most of the 70 materials, the actual physical and chemical behavior once discharged, including their interaction with the many possible water and sediment chemistries, is largely unknown and warrants a great deal of research. While the human hazards of most of the chemicals are known, there are large information gaps in their known effects on aquatic and benthic species.

With the exception of asphalt, sulfur, and perhaps barium carbonate, the preferred response will probably be to remove the material as completely as possible by one of a number of techniques known collectively and generically as dredging. Burial, containment, chemical treatment, sorption, and dispersion are additional ameliorative measures that may be used as interim responses or in cases where recovery cannot be achieved.

Locating and marking the boundaries of a spill, either by active

monitoring or by predictive dispersion models or a combination, is the absolutely essential first step prior to any of the ameliorative responses described herein. This very likely will be one of the most difficult functions in any overall response effort and consequently warrants special attention in near-future research programs.

7.1.2 Dredging

Though largely untested in the role, dredging can generally be considered to be a feasible means of removal of hazardous materials from the bottom of most bodies of water; in the case of land spills, conventional excavation and/or pumping techniques would be analogous. There are a number of different types of dredging systems in operation throughout the United States, each adapted to specific kinds of dredging in specific circumstances. No generalization can be made as to which type of dredge is the best for hazardous material recovery; such a determination must be based on the amount of bottom material which must be recovered, on the environmental setting in which the spill occurred, and in some instances on the character of the material that was spilled. The matrices in Section 4.6 attempt to sort out this complex task. Though all dredges have certain advantages in certain situations and no dredge should be ruled out, especially if it is available, two specific types of dredges can be singled out as having high potential in a variety of situations: the MUDCAT (and any competitors that may arrive on the American market, i.e., Amphidredge) because of its availability and portability; and pneumatic dredges because of their versatility, portability, past use in related roles, and purportedly good operating characteristics (high solids content, low turbidity).

In long-range planning for the use of dredges to recover sinkers, the Coast Guard should be especially aware of the long lead times necessary in conventional dredging due to surveys, contract arrangements, environmental impact assessments, etc. If immediate response of either private or Corps of Engineers dredges is contemplated, particularly for high risk areas, consideration should be given to establishing standby agreements or contracts.

Selection of a dredge system for hazardous material recovery may be strongly influenced by considerations involving the temporary storage, transportation, treatment, and disposal of the contaminated dredged material. Backwards planning, starting with the contemplated disposal method and site, may be the best approach.

7.1.3 Burial

Isolating a hazardous chemical by burying it cannot be considered a permanent solution, as there is always a chance that the chemical will be reintroduced by leaching through or erosion of the cover material. However, burial is a response that could be accomplished with a number of existing or conceptual, but implementable, techniques and it could at least temporarily mitigate the adverse effects of the spilled chemical or be used around the low contaminant level periphery of a spill that had been dredged.

Of the inert materials considered, the fine-grained materials (mainly clays) have the advantages of low permeability, strong adsorptivity, and tendency to spread uniformly and the disadvantages of high erodability (unless consolidated) and high turbidity during emplacement. The coarse-grained materials (sands and gravels), if used for a cover, would settle readily with little turbidity, would tend to resist scouring, but would tend to mound during most emplacement processes and would permit rapid leaching of the buried hazardous chemical. A layered approach or a mixture of fine- and coarse-grained materials may incorporate the advantages of both. Naturally occurring local materials, including nearby uncontaminated sediments, would be the least costly material to use (by an order of magnitude) as well as the quickest.

The eight emplacement methods discussed in detail in Chapter 5 are all considered feasible in certain spill scenarios; the relative merits are condensed in the matrix of Table 5-8. None have been field tested in the hazardous material burial role. In general, however, more accurate, efficient, and uniform coverage could be expected with the pump-down techniques than with the surface discharge (including hand application) and point dump methods.

7.1.4 Other Techniques

Response techniques other than removal by dredging and simple burial have high potential for certain chemicals in certain scenarios. No generalizations can be made since this category includes many unrelated techniques not covered previously. Few of the proposed techniques have ever been attempted in the sinking hazardous chemical spill response role and thus extensive lab and bench testing and field demonstration are indicated.

Containment devices including underwater boom-type barriers, underwater dikes, and trenches appear to have potential to prevent or control dispersion of dense materials on the bottom. They would appear to be most useful in relatively shallow areas with predictable, moderate currents.

Sorbent materials, including activated carbon, polymers, coated cotton, macroreticular resins, and zeolite sieves in various possible configurations suited to submergence, would be valuable against intact masses of liquid contaminants, particularly organics. Recoverable sorbent devices, such as bagged activated carbon, could be an alternative to dredging for small quantities of chemicals in well-defined but difficult or inaccessible areas.

Chemical treatment techniques that are selectively applicable against certain contaminants (though untested) are discussed in the text in both Chapters 5 (Burial) and 6 (Other). They include ion exchange, precipitation, oxidation, and neutralization. Accurate emplacement of the chemicals and cost present difficulties, particularly for large spills and in deep water or high current situations. Chemical treatment agents could be applied in a mixture with inert material (sand, clay, or a mixture of both) to act as a carrier and sealer or in a layer underlying a layer of inert material to hold it in place at least until reaction is complete.

Other covering techniques besides simple burial may have limited application as temporary or permanent sealers. These include grouts and cements, soil sealants, polymer covers, and gels. All these techniques

are strictly in the conceptual stage for underwater use except portland cement-based fixation of contaminated sediments, which has been demonstrated in Japan. Gels and sealants could be more easily applied to land spills.

Biodegradation, though conceptually possible with cultures acclimated to specific chemicals, is not considered generally feasible in the unconfined, current-susceptible circumstances of most spills.

Dispersion and ultimate dilution to the point of harmlessness is not a popular solution, but may be the only one in some, possibly many, spill situations; for example, rupture of a chemical barge in the Mississippi River reach around New Orleans where turbidity, depth, current, traffic, and obstacles all combine to virtually preclude any active response. Dispersants that sink are not currently available.

7.2 RECOMMENDED RESEARCH PLAN

7.2.1 General and Chemical Research

One of the present difficulties in evaluating possible amelioration techniques is the lack of understanding of the fundamental behavior of the sinking chemicals under consideration in the various aquatic and benthic environments. This research area seeks to increase the basic knowledge of sinker spill behavior and includes the following major tasks:

- Dispersion behavior of discharges of hazardous chemicals that sink.
- (2) Physical and chemical interactions between sinking hazardous chemicals and natural sediment/water systems.
- (3) Effects of sinking hazardous chemicals on aquatic and benthic populations.

Outlined below are the objectives, a discussion, and a recommended funding level for each of these three tasks.

Task 1: Dispersion behavior of discharges of hazardous chemicals that sink.

Objectives: To develop the capacity to predict, for various flow

circumstances and environmental settings, the dispersion of discharges of sinking, relatively insoluble, chemicals.

Discussion: The ability to predict dispersion patterns and rates in one- and two-dimensional flow regimes for various size spills of both solids and liquids would be an invaluable advancement and aid in responding to sinker spills. Research should follow three approaches:

- (1) mathematical/computer modeling; (2) physical modeling; and
- (3) real-time prototype sampling and monitoring of simulated spills. Results could be incorporated into CHRIS for field use and should receive funding for continual refinement and updating.

Estimated Funding: \$750K

<u>Task 2</u>: Physical and chemical interactions between sinking hazardous chemicals and natural sediment/water systems.

Objectives: To develop a better understanding of the interaction between sinking hazardous chemicals and the various sediment environments and water chemistries that could be encountered.

Discussion: Research under this task should deal with specific chemicals that are: (1) most hazardous or (2) transported in greatest quantities, or both, or else with representative chemicals from classes that share many physical and chemical behavior characteristics (e.g., liquid halogenated hydrocarbons). The first and most needed step is a complete literature search followed by lab work to determine adsorption or ion exchange characteristics of specific chemicals in various sediment types in various typical aquatic or marine chemical environments. Also necessary is work to ascertain the extent and rates of reaction with water-reactive chemicals (e.g., lithium aluminum hydride, calcium oxide) in simulated natural waters and spill scenarios. Precipitation reactions that could occur in natural waters (e.g., $BaCO_3 + SO_4^2 + BaSO_4^4 + CO_3^2$) should also be investigated thoroughly. Initial lab work should be followed by controlled pilot-scale field studies with actual hazardous chemicals in small, isolated bodies of water.

Estimated Funding: \$500K

Task 3: Effects of sinking hazardous chemicals on aquatic and benthic organisms.

Objectives: To achieve a more complete, reliable, and consistent information base on the type and extent of hazards posed by each of the 70 chemicals on representative aquatic and marine free swimming and benthic species.

Discussion: Existing information needs to be exhaustively collected and standardized to the extent possible and glaring deficiencies identified. As part of the initial literature search the CHRIS should be updated and improved in this area. Bioassay work should be undertaken to fill information gaps with first priority given to those materials presumed to be most hazardous. Extensive work is needed to determine the tendency to bioaccumulate of many of the 70 chemicals.

Estimated Funding: \$800K

7.2.2 Dredging Research

Dredging is the only anticipated feasible means of recovery of hazardous chemicals in significant quantities from the bottoms of waterways. With the exception of the few cases brought out in Chapter 4, it is largely untried and untested in this role. The ratings given in Tables 4-8 - 4-11 rely upon extrapolation of known characteristics to the new role and need to be objectively verified and/or modified through comparative testing. Additional basic research and development need to be accomplished to incorporate new ideas and designs to facilitate effective and safe hazardous chemical retrieval. The following basic tasks are proposed in the dredging research area:

- (1) Comparative evaluation of selected existing dredge types.
- (2) Demonstration and evaluation of state-of-the-art systems.
- (3) Conception, development, and demonstration of new equipment tailored to hazardous material recovery.

Each of these three research tasks is outlined below:

Task 1: Comparative evaluation of selected existing dredge types.

Objectives: To obtain objective and directly comparative information on operating parameters pertinent to hazardous material recovery of the major conventional dredge types in various spill settings.

Discussion: Accomplishment of this task will fulfill the basic

need to test and evaluate dredges in the hazardous material recovery role. As many different dredge types as possible should be directly compared in several representative settings against a number of different sediment/simulated chemical configurations (e.g., adsorbed liquid, loose solid, free liquid, etc.). Each operation should be monitored for: vertical and horizontal accuracy of cut; degree of turbidity and contaminant resuspension caused; completeness of contaminant removal; efficiency of contaminant removal (concentration of contaminant in dredged slurry); effectiveness in currents, waves, tight spots, etc. The results of a truly comprehensive testing program such as that described would go far toward increasing the objectivity and confidence with which dredges could be selected for recovery jobs. Results would also be of general value to the dredging industry by adding to the fund of knowledge on environmental impacts. It is recognized that the expense and difficulty of mounting a comprehensive program would be great, even if a willing contractor could be found. However, any somewhat standardized testing of individual dredge plants in the hazardous material recovery role would advance the state of the art. The first step in any such program is to develop the specific testing procedures and standards for comparison.

Estimated Funding: \$1.4M

Task 2: Demonstration and evaluation of state-of-the-art systems.

Objectives: To evaluate state-of-the-art systems for effectiveness in hazardous material recovery.

Discussion: This work should parallel that of Task 1 above or perhaps precede it. Those systems—such as the pneumatic dredge pump, the Cleanup dredging head, closed clamshell buckets, the Amphidredge and MUDCAT, the entire TST system—which may now be considered high potential or state of the art should be objectively evaluated to verify or disprove claims and ascertain special advantages. Testing should be against a standard similar to that in Task 1 above. Successful or very successful results could conceivably preempt further evaluation of other systems and lead to procurement.

Estimated Funding: \$1M

<u>Task 3:</u> Conception, development, and demonstration of new techniques and equipment tailored to hazardous material recovery.

Objective: To advance the state of the art of hazardous material recovery through encouragement of creative development of novel equipment and techniques.

Discussion: This task is envisioned to be an essentially open request for proposals for any item or procedure, large or small, that would add to the capability of present systems or constitute a new system for more effectively and efficiently recovering hazardous materials from the bottom and related activities. Possible items include: new or improved dredging heads to minimize resuspension; a floating dredged material treatment/decontamination plant that operates in-line with the dredge; onboard or ladder-mounted sensing and monitoring devices to facilitate accurate detection and efficient retrieval of contaminants; and an epoxy- or Teflon-lined pneumatic dredge capable of using compressed CO, as a working gas for recovering corrosive and/or flammable materials. Administration of this program would have to be flexible as would funding levels. However, it is felt by the authors that somewhere in the program there must be an opportunity for creative research and development that leads to new technology and hardware. Emphasis should be placed on mobility and fast response.

Estimated Funding: Not provided.

7.2.3 Burial Research

Understanding of dispersion and coverage characteristics, scouring tendencies, leaching potential, and environmental impacts of the various materials and techniques discussed in Chapter 5 is not adequate. A great deal of research is needed into the basic phenomena involved, as well as development and testing of the emplacement methods proposed, using various materials. However, it is felt, due to the secondary role of burial as a desirable response and the fact that burial could be accomplished in any case with existing means, that burial research should receive a lower priority than the basic general research, dredging research, and some of the "other techniques" research. Recognizing this,

the following research tasks are nevertheless proposed:

- Study of in-place properties and effectiveness of selected inert materials as burial covers of selected hazardous materials.
- (2) Emplacement system development and demonstration.

Details of these two research tasks are given below:

<u>Task 1</u>: Study of in-place properties and effectiveness of selected inert materials as burial covers of selected hazardous materials.

Objectives: To ascertain the ability of various types of potential inert burial materials to effectively isolate various classes of hazardous chemicals and to determine scouring properties.

Discussion: This task must build on previous work (detailed in Chapter 5 and Appendices D and E) to develop a more complete understanding of the effectiveness of clays, silts, sands, gravels, and mixtures and layered applications in sealing off individual and categories of hazardous chemicals that sink. Particular attention must be paid to necessary depths to retard leaching of various chemicals and to the ability of each type of cover to resist scour and erosion. Both an empirical approach as well as an effort to better explain the physiochemical mechanisms involved should be combined in this effort. An initial lab phase followed by bench and field work is envisioned.

Estimated Funding: \$400K

Task 2: Emplacement system development and demonstration.

Objectives: To develop the hardware and operational techniques for implementation of selected high potential burial material emplacement systems and to field-evaluate each system for various cover materials in various spill scenarios, including dispersion characteristics and coverage effectiveness.

Discussion: This task should probably be divided into subtasks by equipment item. The three items with the best potential and that require the most development prior to demonstration are: (1) submerged discharge dredge pipe with diffuser (diffuser is critical item); (2) hopper dredge pump-down system; and (3) spray boom system for hopper dredge. These three systems, once prototypes are developed, should receive

systematic field evaluation as should the other techniques (such as surface dredge pipe discharge) that do not require hardware development. Results of field tests would provide objective assessments of the suitability of the various systems in each scenario with each cover material.

Estimated Funding: \$1M including equipment costs

7.2.4 Other High Potential Techniques Research

Further research should be organized around the categories of responses used in Chapter 6 of this report (i.e. containment, covers, sorbents, and chemical treatment). Many of the techniques discussed have high potential for specialized use against certain sinkers, but extensive lab work and field verification would first be necessary. Each of the categories of responses is treated as a research task and discussed below.

Task 1: Containment techniques

Objective: To determine the effectiveness of and construction/ deployment guidelines for submerged dikes, trenches, and artifical spill barriers for use to contain or limit the spread of a mass of hazardous material on the bottom and/or to contain or control the application of cover materials.

Discussion: Containment techniques, though not a solution to a spill in themselves, can be valuable in limiting its dispersion on the bottom until dredging or other responses can be mounted. Research in this area should investigate the effectiveness of each type of barrier in stopping the flow or dispersion of representative chemicals from each category in various current situations, including still water, high and low one-directional current, and shifting or random currents. Both bench scale and limited field demonstrations (with simulated hazardous chemicals) would be appropriate. Consideration should be given to height (depth) of barriers, cross-sectional shape, location and plan configuration relative to spill center and prevailing currents, and equipment and techniques for constructing or emplacing the containment barriers. Use in containing/controlling burial material mudflows should also be investigated.

Estimated Funding: \$700K

Task 2: Covering Techniques (other than conventional burial)
Objectives: To develop, demonstrate, and evaluate the underwater use of grouts and cements, soil sealants, polymer covers, and gels to permanently or semipermanently fix, seal, and contain a contaminant in place on the bottom.

Discussion: This task involves a variety of techniques as discussed in Chapter 6 and should probably be broken into subtasks by type of cover. There is considerable background in the use of grouts and cements, and investigation may involve bench, pilot, and field testing of these materials and techniques (e.g., DCM, Japan) on real or simulated hazardous chemicals. Soil sealants, principally commercial clays such as bentonite, should be lab tested against specific chemicals and field tested to determine application techniques. Soil sealant research may overlap with or possibly fall under the burial research area. Polymer covers, of various types and several application methods (discussed in Chapters 5 and 6), need prototype development and testing for sealing effectiveness, durability, ease of emplacement, etc. A heavierthan-water universal gelling agent would be a useful developmental item.

Estimated Funding: \$800K including equipment

Task 3: Sorbents

Objective: To develop and evaluate sorbent materials, packaging configurations, and deployment and recovery methods for use against specific or classes of sinking hazardous chemicals.

Discussion: Although activated carbon and various polymeric and natural sorbent materials are currently available and would be effective for use against a wide range of organics, there is a need to develop packaging, deployment, and even recovery schemes so that the sorbents may be effectively used under water in various scenarios. One proposed system, considered as high potential, is a recoverable sorbent boom which would serve to contain as well as adsorb a spill. Current research into magnetized activated carbon for response recovery should be followed closely. Macroreticular resin and zeolite sieves require considerable research to ascertain uses in the present role; they are

currently too costly to be considered high potential.

Estimated Funding: \$500K

Task 4: Chemical Treatment

Objectives: To develop a better understanding of specific chemical treatment methods for use against specific spilled materials and to evaluate effectiveness, dosage criteria, and application techniques.

Discussion: Although the basic chemistry of each of the 70 sinkers is known and possible chemical treatment techniques can be speculated upon, as has been done in this report, a great deal of research is needed to ascertain specific reaction behavior in real or simulated spill settings, rates of reaction, and dosages and means of application of treatment reagents. An exhaustive literature search should be followed by extensive laboratory simulation and field testing of the most promising techniques. A refined and verified list that matches sinking hazardous materials with a large number of treatment strategies would be a result of this research. Basic subtasks should be broken down by type of reaction, i.e., ion exchange, precipitation, oxidation, and neutralization. Deployment and application techniques for chemical agents would be related to techniques for some sorbents, and research should be coordinated to preclude duplication.

Estimated Funding: \$800K

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APPENDIX A: PCB TRANSFORMER SPILL* SEATTLE, WASHINGTON

A.1 THE ACCIDENT

On 13 September 1974, an electrical transformer was dropped while being loaded onto a commercial barge resulting in 265 gal of Aroclor 1242 polychlorinated biphenyls (PCB) being spilled into the Duwamish Waterway.

The Duwamish Waterway is an important navigational channel within the City of Seattle. The Lower Duwamish River is affected by tides of up to 13 ft and regularly flows at approximately 4 knots. The spill site, near river mile 1.5, is predominately a mud/silt bottom, has fresh water overlaying a saltwater wedge, and is approximately 45 ft deep and 500 ft wide. The Duwamish River empties into Elliott Bay and supports one of the many anadromous fish runs in the Puget Sound area (Figure A.1).

The 75 KVA transformer involved was made by Westinghouse and has an internal coolant liquid capacity of 283 total gallons. According to the manufacturers specifications tag, the PCB coolant was Enerteen, a mixture of 70 percent PCB (Aroclor 1254) and 30 percent trichlorobenzene. However, laboratory examination disclosed the coolant had been changed to 100 percent PCB (Aroclor 1242), specific gravity 1.4, probably because it would perform better in the extreme climate of the Arctic.

The transformer was crated in plywood and bolted to skids on the crate bottom. On the exterior of the crate there appeared the directions "lift by base only" and the center of balance was designated. There were no markings indicating the potential hazards of the transformer coolant. The upper corners of the crate were fully enclosed and were not cut off to expose the corner metal lifting "ears" on the

^{*} Reprinted from an article by James C. Willman, Chief, Environmental Emergency Section, U. S. Environmental Protection Agency, Region X.

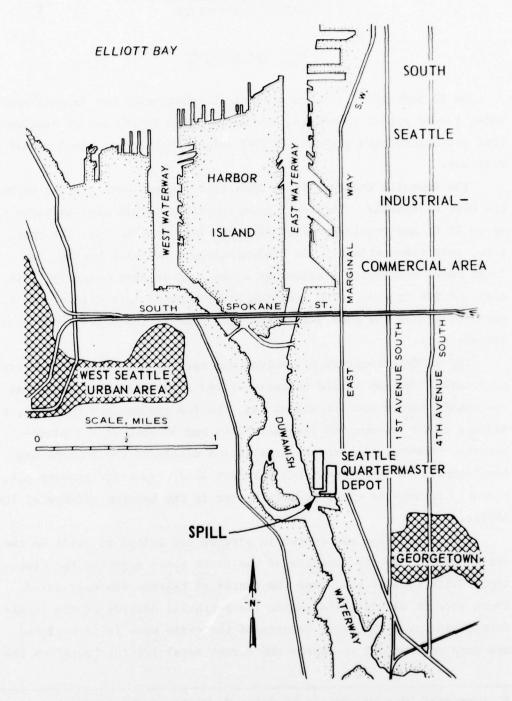


FIGURE A-1. PCB SPILL LOCATION (13 SEPTEMBER 1974).

metal transformer case. In previous instances of transformer shipment, the packing crates had the upper corners cut off, thereby exposing the metal ears on the top of the transformer cases which were utilized to hoist the transformers. However, as this was to be a water shipment, the unit was sealed.

The spill was reported to the U. S. Coast Guard (USCG) in Seattle as a minor oil spill. A Seattle oil cleanup contractor, Marine Oil Pickup Service (MOPS), contracted by APUTCO, responded and removed some 4 gal of floating material. The initial spill report did not reveal the involvement of PCB. On 16-17 September, a follow-up investigation by both the Washington State Department of Ecology (DOE) and USCG determined that the transformer coolant was PCB and not an oil spill. DOE requested Environmental Protection Agency (EPA) assistance to locate and quantify the spill in the waterway. EPA also initiated investigations into alternatives for possible removal and disposal of the spilled material.

A.2 ASSESSING THE MAGNITUDE

On 18 September, an EPA Region X laboratory team collected and analyzed some 29 bottom samples in the vicinity of the accident (Figure A-2). The analytical results indicated the material had remained in two general areas, one immediately adjacent to the dock where the spill occurred and the second further out in the Duwamish River. After reviewing data on 23 September, EPA representatives met with Seattle USCG and Department of Defense (DOD) representatives involved in the incident and requested DOD or the shipper to assume responsibility for the incident and initiate cleanup. Responsibility was refused whereupon EPA assumed the On-Scene-Coordinator (OSC) role, as prescribed by the Regional Oil and Hazardous Material Contingency Plan, for cleanup of the pollutant.

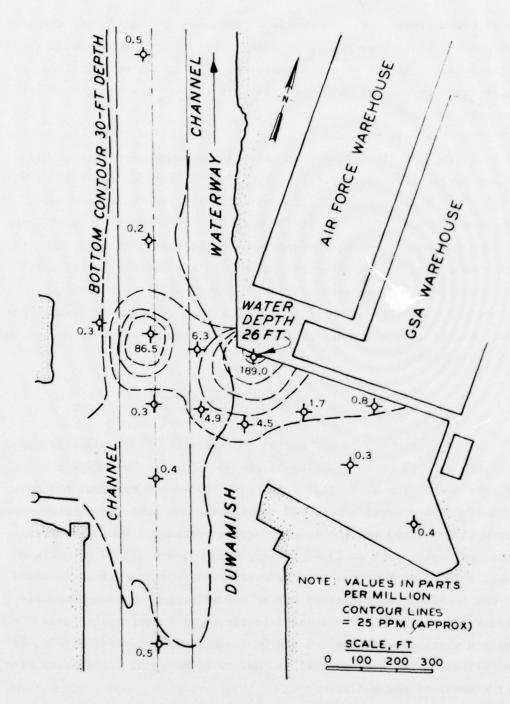


FIGURE A-2. PRECLEANUP - PCB SEDIMENT CONCENTRATIONS (18 SEPTEMBER 1974).

A.3 CLEANUP POTENTIAL

EPA divers deployed on 26 September observed pools of free PCB material on the bottom. They concluded that a dredging program to remove the contaminated material could be successfully carried out.

Several alternative actions were outlined, including those below:

- a. Utilize hard hat divers pumping water and contaminated sludge into a Navy 100,000-gal barge. This operation would require additional facilities to offload the barge, treat the effluent, and dispose of the sludge.
- b. Utilize a 22-in. pipeline dredge to remove some 8,000,000 gal of water and PCB-contaminated mud onto Kellogg Island, which is immediately across the waterway from the site, and is owned by the Port of Seattle and presently used as a dredged material disposal site by the Corps of Engineers. This operation would require constructing several large ponds by moving some 30,000 yd of material. It would also be necessary to construct impervious liners for the ponds for complete retention of all fluids. It was estimated that the dredging operation could be performed in 1 day, assuming all site preparation had been completed.
- c. Utilize divers with small handheld dredges pumping water and spill material through presettling tanks and using EPA's transportable physical/chemical treatment unit located in Edison, New Jersey, to treat the return water.

Evaluation of the three alternates resulted in the initial selection of the second approach. The first alternative was eliminated because of the lack of adequate barge-holding capacity in the area together with the lack of subsequent sludge disposal site for the contaminated mud. Logistics problems associated with the third approach resulted in its initial rejection.

On 2 October, after an onsite visit by a team of geologists from EPA, Corps of Engineers, and DOE, it was decided that the necessary holding ponds could not be economically constructed due to poor soil characteristics. The need to retain all effluent and sludge made it necessary to completely seal the ponds in order to prevent any seepage or runoff. It was estimated that 30 days or more would be required to construct the ponds and cost more than existing funds would allow.

Logistic problems such as access to the island, construction, etc., were reviewed with military personnel from the 6th Army, Ft. Lewis, and the 13th Naval District; use of the island was then eliminated. Based on these data, this alternative was eliminated and the third alternative was selected.

During the investigation period discussions were also being held with the technical staff at the EPA Edison, N. J., Industrial Environmental Research Laboratory regarding use of the transportable physical/chemical treatment unit. The unit is a mobile wastewater treatment plant utilizing primary settling, mixed media pressure filters and activated carbon columns. It was hoped its use would reduce PCB in the return water from the settling of the dredged material sufficiently to permit immediate discharge back to the waterway. Because this unit was used successfully in a spill incident involving pesticides on the east coast, it was decided to utilize the system in the Duwamish spill.

A.4 CLEANUP PROCEDURE

A.4.1 Phase I

On 3 October the unit was activated and on 4 October it departed Edison, New Jersey, arriving in Seattle on 9 October. Dredging began on 12 October. DOE conducted tests using alum, ferric chloride, and lime and Nalco 634, a polyelectrolyte to determine the most satisfactory settling rates of contaminated sludge. Nalco 634, at 20 mg/ ℓ , provided the best settling of any of the material tested. On 31 October, after containing the initial treated effluent in holding tanks pending favorable laboratory results, the first operational discharge was approved as the final effluent contained only 0.075 μ g/ ℓ PCB (Table A-1). The disposition of spill recovery equipment is shown in Figure A-3.

The dredging operation lasted some 20 days resulting in the processing of approximately 600,000 gal of water and the collection of 215 drums of PCB-contaminated mud which was stored temporarily in the Air Force warehouse. Ultimate disposal of the drums was carried out by DOD in the spring of 1975 at a Federally recognized hazardous waste disposal

Table A-1
Initial Treatment Plant Results

Sampling Location	PCB Concentration, $\mu g/\ell$
First Settling Tank	400
Second Settling Tank (Swimming Pool)	400
After Sand Filter	3.5
Final Effluent After Carbon Columns	0.075

Sludge Concentrations

Low 4 parts per thousand
High 30 parts per thousand

Average - 1-2 percent PCB in Barreled Sludge

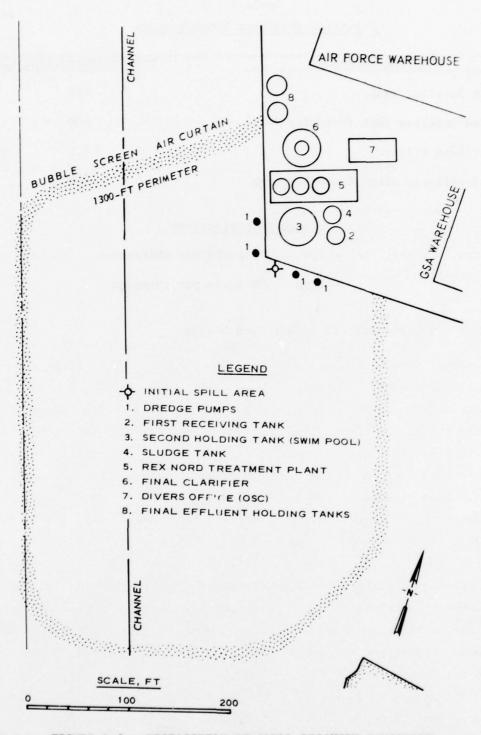


FIGURE A-3. DISPOSITION OF SPILL RECOVERY EQUIPMENT.

site near Twin Falls, Idaho. This site uses abandoned Titan missile silos for secure containment.

The highest concentration level of PCB recovered was found in the initial spill area. However, there was evidence that the river current and tidal action had caused pockets of PCB to move about. Divers observed pools of PCB moving as much as 50 ft with the tide from 1 day to the next.

Concentrations of PCB in the recovered mud indicated that approximately 70 to 90 gal of the material was removed during the operation. While visual observations of the material on the bottom surface indicated most of the free PCB had been removed, it was evident, based on bottom sampling, that concentrations of PCB remained high in the sediments within the spill impact area.

On 31 October, the project was terminated as it was determined that the operation had changed from one in which dredging was effective to one which would require a substantially larger effort, ultimately the removal of some 40,000 cu yd of bottom material from the barge slip area in which the spill occurred. In some cases, the divers had dredged the bottom muds up to 20 in. deep and had continued to note droplets of PCB in the sediments. A sampling program conducted during the latter part of the removal operation revealed that substantial quantities of PCB remained tied up in the bottom sediments. Concentrations substantially higher than background were also noted out to midchannel. It was estimated that the contaminated area covered approximately 200 by 500 ft (Figures A-4 and A-5).

A.4.2 Phase II

Pursuant to EPA efforts, DOD assumed responsibility for the spill incident in February 1975 and subsequently delegated further removal efforts to the U. S. Army Engineer District, Seattle. Funding for the cleanup project was the responsibility of the Army Materiel Supply Command, Tooele, Utah.

EPA Region X laboratory staff carried out a continuing monitoring program from 18 September 1974, 5 days after the spill, throughout 1975, to April 1976. Although most of the material remained in the

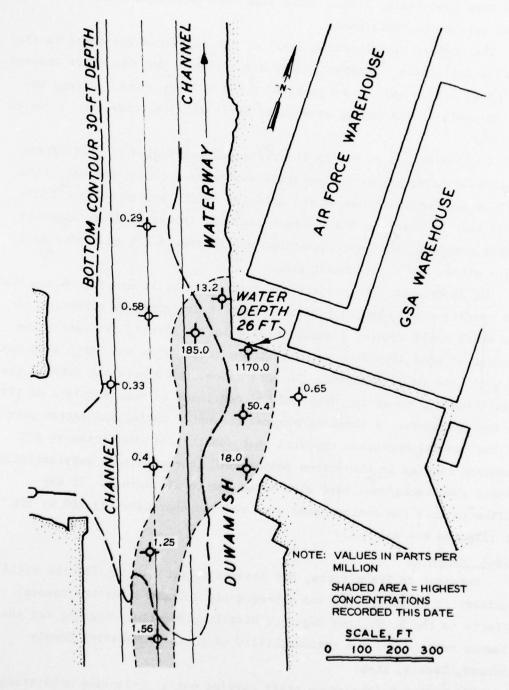


FIGURE A-4. POSTCLEANUP - PCB SEDIMENT CONCENTRATIONS (4 NOVEMBER 1974).

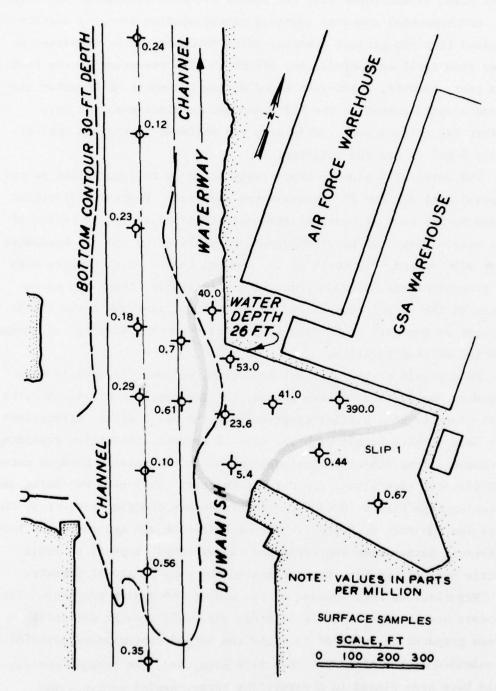


FIGURE A-5. PCB SEDIMENT CONCENTRATIONS (2 JUNE 1975).

spill area, it was shown that PCB slowly migrated throughout the slip.

Environmental concerns centered around pending dredging operations required that the project commence after November and be completed no later than April to minimize any effect on fish resources of the area. This year, however, a 100-year flood during the month of December dispersed a small pocket of the PCB pollutant in midchannel out into Elliott Bay (Figure A-6). This area was believed to contain approximately 5 gal of the PCB pollutant.

The Corps of Engineers tentatively selected Kellogg Island as the disposal site for the PCB-contaminated sediment. However, objections raised by the Port of Seattle ultimately resulted in the rejection of this site. Next, the Corps discussed possibly using the old treatment plant site immediately north of the Federal Center South Complex with the present owners, Chiyoda Industries. Initially, there was no response to the Corps' request and it was assumed that there was little interest on the part of Chiyoda to negotiate for the disposal of dredged material at this location.

As a result of the apparent rejection, serious discussions were held with Manson Construction Company for the use of their South Parks Court property some 2 miles upstream from the spill site. Discussions were held simultaneously with the City of Everett authorities regarding placement of the PCB-contaminated material in the current dredged material disposal site within the City of Everett. This area was being used in conjunction with a 180,000-cu yd maintenance dredging project by the Corps for the Port of Everett. Use of this site was denied by the Port of Everett authorities who expressed concern over disposal of toxic Seattle material within the confines of the city limits of Everett.

Negotiations then focused on the use of the Manson property. This property covers approximately 24 acres and would require extensive access preparation in order to allow the barged contaminated material to be unloaded at the site. If this site were used, the dredged material would have been placed in a watertight barge, hauled upriver, and off-loaded by pipeline into a large earth pit. The pit then would subsequently be filled with the contaminated material and covered with

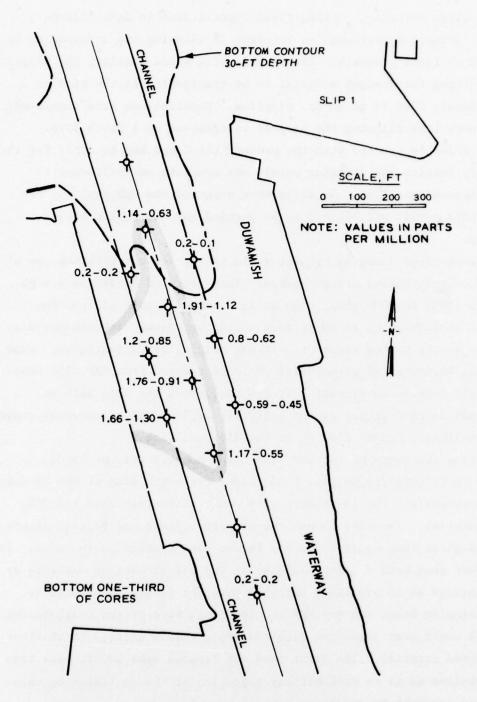


FIGURE A-6. PCB SEDIMENT CONCENTRATIONS (18 JUNE 1975).

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3 ft of clean material. During final negotiations in late December, Chiyoda Industries expressed an interest in allowing the material to be disposed on their property. Use of this site would simplify the project by permitting the dredged material to be transported to the site by approximately 2500 ft of 10-in. pipeline. Negotiations were completed in February thus allowing the project to commence on 1 March 1976.

In order to proceed with the project the Corps had to apply for the necessary Section 404 dredging permit and complete an Environmental Impact Assessment (EIA). As sites were selected and subsequently rejected this permit and EIA had to be amended and the Public Notice reissued.

The proposed dredging project would be carried out with the use of a Chicago-based Pneuma dredge system. This patented dredge is a high capacity (2000 to 3000 gpm), high solids dredge capable of removing material containing up to 80 percent solids by volume with minimum disturbance to the bottom sediment. It was originally estimated that some 30,000 to 40,000 cu yd of material would be removed from the slip area. This would require an average 2-ft cut throughout the slip with an additional 3- to 4-ft cut at the spill site. The dredged material would be hydraulically pumped 2500 ft to the disposal site.

During the month of February the Corps constructed two large 250,000 cu yd capacity holding ponds along the north side of the 25-acre Chiyoda property. The 15-ft-deep pits would ultimately hold the PCB-laden material. In order to use the property, State and Federal assurance was given that would allow for future construction on the site. It was agreed that back filling would be at the specifications outlined by the owners so as to provide a suitable base for future construction. The Washington State DOE and EPA required that none of the contaminated material would ever leave the site and would remain under 3 ft of clean undisturbed material. The first pond was located some 200 ft back from the shoreline so as to prohibit any migration of the contaminated material back into the Duwamish.

To aid the treatment process, NALCO 7134 was injected into the pipeline about 200 ft before the material entered Pond 1. It was found

that by adding this cationic polyelectrolyte at 20 mg/l the solids settled near the influent resulting in very little turbidity entering Pond 2. Tests showed that water entering Pond 2 had a turbidity of about 17 Jackson Turbidity Units (JTU).

The water pumped periodically from Pond 2 through a "Filtrite" cartridge filter system at 1000 gpm into a small 10,000-gal plastic lined holding pond. Various tests were conducted with the Filtrite unit and it was found that the $100-\mu$ size cartridges provided the best overall removal of algae and suspended solids. This smaller pond served as a surge pond to allow for continuous use of the final treatment unit, an EPA physical/chemical treatment truck from Edison, New Jersey.

The Edison physical/chemical treatment unit, which also assisted in the first PCB cleanup operation in October 1974, consists of three mixed media pressure sand filters followed by three activated carbon columns. While the truck was designed for a flow rate of 200 gpm utilizing the system in series, it was found that the turbidity and PCB concentrations were sufficiently low to permit by-passing the sand filters and using the three carbon columns in parallel. This permitted running 600 gpm through the unit rather than the 200 gpm for which it was designed. The effluent was pumped 70 ft to an abandoned 30-in. sewer line which discharged into the Duwamish River.

An extensive monitoring program was carried out during the operation to ensure (1) that the PCB contaminated sediment was removed from the waterway and (2) that the contaminant did not return to the Duwamish through the treatment process. Both predredge sediments and sediments taken during the dredging operation were analyzed for PCB content in order to establish the degree of PCB contamination remaining in the slip. Generally, the dredged area was found to be free of PCB after about a foot of sediment was removed. However, at the spill site where it was originally thought that 4 ft of dredging would be required to reduce the 2,000-mg/k concentration, it was found that the bottom still contained about 200 mg/k after 6 ft of material had been removed. Additional dredging to a depth of about 10 to 12 ft to hardpan in this area resulted in PCB concentrations of about 10 mg/k.

PCB concentrations entering Pond 1 were about 8 to 10 mg/ ℓ . After centrifuging, 40 µg/ ℓ remained in the water column. The concentration of PCB was drastically reduced during the treatment period. Less than 0.05 µg/ ℓ was entering the EPA treatment unit and a negligible amount leaving.

A.5 DISCUSSION

The EPA treatment unit arrived in Seattle on 1 March and dredging began 6 March. It is estimated that 12,000 to 15,000 cu yd of material was removed during the 30-day operation. It is also estimated that no more than 25 percent solid removal was accomplished during this period. This may be attributed to skimming of the top layer of bottom sediment with the exception of that dredged at the spill site. Numerous breakdowns and delays were encountered due to bottom debris, relocation of the dredge, and other more minor problems. During the month approximately 9.5 million gal of water was treated and returned to the Duwamish Waterway.

On 31 March, the dredging terminated and on 12 April after treating most of the remaining water in the ponds, the EPA treatment unit departed. Based on sampling conducted during the final phase of the operation, it was estimated that approximately 140 to 150 gal of PCB was removed during this operation (Figure A-7). Added to the 70 to 90 gal removed during the initial phase, it is estimated that 210 to 240 gal of the original 250 gal of PCB spilled was removed. While final costs have not been tabulated, it is estimated the project cost about \$370,000 (See Table A-2). This, together with the initial cost of \$120,000, brings the total expenditure to nearly \$500,000 to remove the 240 gal of Aroclor 1242.

A.6 CONCLUSIONS

The following conclusions were drawn:

a. The overall project was a success in that a vast majority of the PCB was removed.

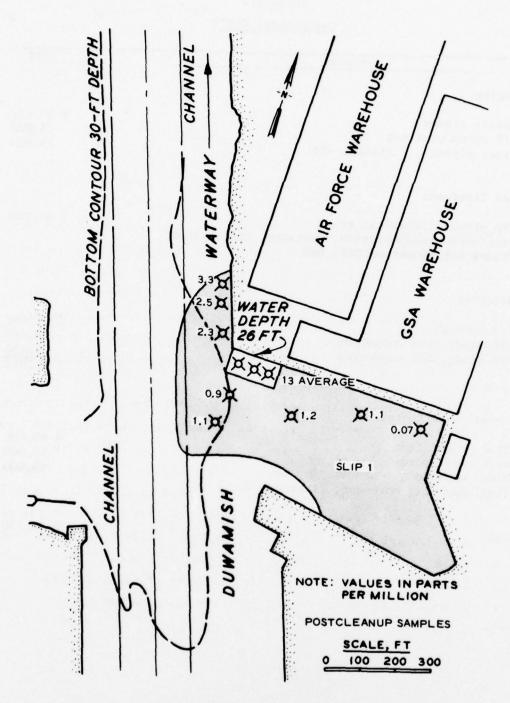


FIGURE A-7. PCB SEDIMENT CONCENTRATIONS (APRIL 1976).

Table A-2
Operational Cost*

Process	Cost
Dredging	
Pneuma dredge	\$ 80,688
C/E barge plus tug	13,000
Misc. pipings, fittings, etc.	15,000
Water Treatment	
EPA physical/chemical truck	\$ 64,000
(includes transportation, operator, contingency) Figure not to exceed \$123,000	
Monitoring	
PCB removal	\$ 34,600
EPA study, WES supported	17,012
EPA study, EPA supported	9,430
	\$ 61,042
Disposal Site Rental	
Site preparation	\$ 60,000
Back cover ponds	50,000
Misc. expense	40,000
(Includes ship movement, fittings, etc.)	
Total	\$418,730

^{* 15,000} to 20,000 cu yd of material removed, 30 percent solids.

- $\underline{\mathbf{b}}$. It also indicated that bottom sinker toxic substances spilled, under similar circumstances, tend to remain in the area and can successfully be removed even after a significant period of time.
- while the expenditures appear high, it can be shown that future operations could be modified so as to considerably reduce the cost in removing these toxic materials.
- $\underline{\mathbf{d}}$. PCB has a strong affinity for particulate matter and, once these sediments are removed and dewatered, can be disposed of in a satisfactory landfill operation.
- e. To achieve even a higher success, immediate response actions are required to remove these pollutants from the spill site.
- $\underline{\mathbf{f}}$. Dredging methods must be evaluated as to the type of sediment removed and potential pollutant dispersion throughout the 'water column.

APPENDIX B: PNEUMA SYSTEM

Pneuma dredging pumps are built in various standard configurations, but the most common arrangements are those shown in Figures B-1 and B-2. Both are identical except for the excavator design: one has three individual scoops and the other has an integral scoop. Table B-1 gives sizes and weights of various Pneuma pumps.

Regardless of the underwater configuration, all Pneuma pumps require a manifold. The typical manifold is depicted in Figure B-3 and sizes and weights are given in Table B-2.

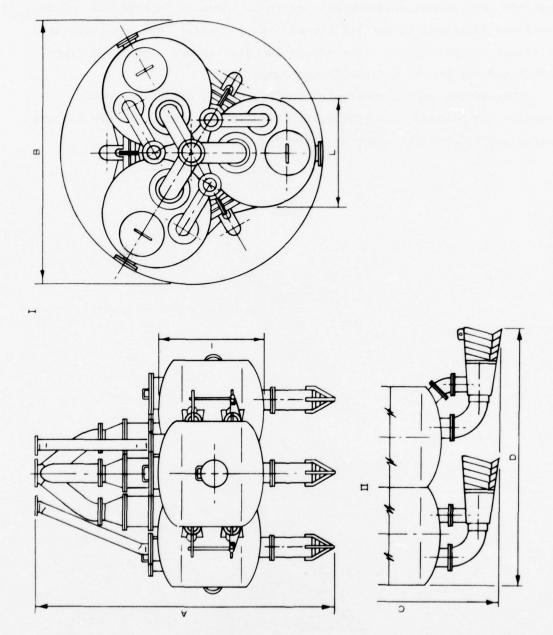


FIGURE B-1. THREE SCOOP "PNEUMA" SYSTEM.

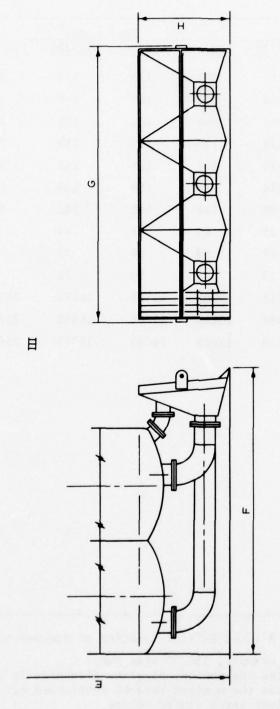


FIGURE B-2. SINGLE SCOOP "PNEUMA" SYSTEM.

Table B-1
Pneuma Pump Sizes

Dimensions			Pum	Model ^b		
in.	150/30	300/60	450/80	600/100	1200/150	1500/200
Α	144	161	173	173	224	244
В	104	122	147	147	181	181
С	126	146	161	165	224	244
D	118	130	159	159	191	193
E	126	147	161	161	224	244
F	114	126	158	158	185	185
G	98	114	142	142	165	165
н	35	43	47	47	47	47
I	47	59	59	79	98	118
L	39	47	59	71	71	71
Weight I, 1b	6615	9261	12569	14774	24917	30429
Weight II, 1b	7387	10143	13781	16538	25799	29327
Weight III, 1b	8159	11025	14663	16979	26687	30429

Refer to Figure B-1 and B-2 for location of dimensions.

b Model code, for example, 150/30 size pump:

¹⁵⁰ indicates the nominal pipeline discharge in cu m/hr.

30 indicates the nominal rate of compressed air in cu m/min to deliver rated slurry volume.

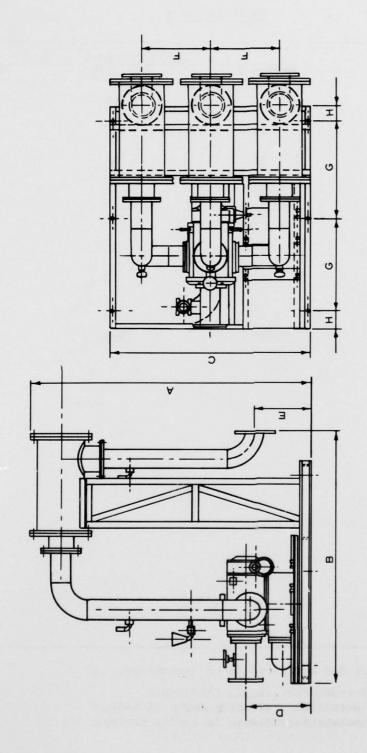


FIGURE B-3. "PNEUMA" MANIFOLD SYSTEM.

Table B-2 Manifold Sizes

Dimensions		Manifold Model ^b	
in.	UN3/3C/R	UN4/3C/R	UN5/3C/R
A	84	89	97
В	75	78	91
С	51	63	87
D	20	21	28
E	20	20	24
F	18	22	29
G	27	27	34
Н	8	8	8
Weight, 1b	2867	3969	5513

a Refer to Figure B-3 for location of dimensions.

b Manifold model code, for example UN4/3C/R:

UN4 - generalized size designation (3<4<5).

3C/R - number of cylinders in configuration.

APPENDIX C: DREDGE DIRECTORY*

To aid the Coast Guard in assessing the availability of dredging equipment, this directory lists by state all the known inventories of dredging equipment located in the United States as of January 1977. Abbreviations for the various equipment types listed in the directory are defined below.

MECHANICAL	HYDRAULIC	MISCELLANEOUS		
BB - Bucket Backhoe BC - Bucket Clamshell BD - Bucket Dipper BG - Bucket Grab BL - Bucket Ladder	CS - Cutter Suction HS - Hopper Suction S - Suction SD - Suction Dustpan TH - Trailing Suction Hopper	BS - Booster Station HB - Hopper Barge		

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		PII	PEL	INE SIZI	E	PUMP	DREDGE
DREDGE	OR	BUCKET	OR	HOPPER	CAPACITY	HORSEPOWER	TYPE

ALABAMA

Aliceville Sand & Gra	avel Co., Aliceville	35442	
"No. 2"	10 in.	<u></u>	CS
"No. 1"	12 in.		S
"No. 3"	12 in.		S
"No. 4"	10 in.		S
"No. 5"	10 in.		S
"No. 6"	10 in.		S
Bender Welding & Mac	nine Co., Inc., P. O.	Box 42, Mobile 36601	
"Dredge Mobile"	16 in.		CS
"Mary B"	10 in.		CS
Coosa Pile Driving Co	o., 912 Edgewood Dr.,	Pell City 35125	
"Grace D"	14 in.		CS
"Donna-Jo"	10 in.		CS
"Not named"	6 in.		CS
Radcliffe Materials,	Inc., P. O. Box 2068,	Mobile 36601	
"Gu11"	22 in.	1500	CS
"Mallard"	18 in.	1200	CS
"Albatross"	16 in.	1000	CS
"Flamingo"	16 in.	500	CS
"Shearwater"	12 in.	300	CS
"Pelican"	16 in.	500	CS
"Mr. R. B."	16 in.	500	S
"Avocet"	2-16 in.	500	S
"CFM"	12 in.	300	S

ALASKA

Alaska Dredge & Concrete	, Inc., P.	O. Box 2307,	Ketchikan 9990	1
"No. 1"	10 in.			CS
Goodnews Bay Mining Co.,	Platinum	99651		
"Yuba"	8 cu ft			BL

	PIPELINE SIZE	PUMP	DREDGE
DREDGE	OR BUCKET OR HOPPER CAP	ACITY HORSEPOWER	TYPE
	ALASKA (continued)		
UV Industries Inc., P.	O. Box 1170, Fairbanks	99707	
"Hogatza"	6 cu ft		BL
			DL
	ARKANSAS		
Arkansas Valley Dredgin	g Co., Inc., P. O. Box	548, Benton 72015	
"Dredge No. 11"	18 in.	1325	CS
Arkhola Sand & Gravel C	o., 321 Merchants Bank	Bldg., Ft. Smith	72901
"Walter S."			
"Dills"	14 in.	1650	cs
W. D. Jeffrey Construct	ion Co., P. O. Box 998,	Ft. Smith 72901	
"Rosie Lee 14"	14 in.		CS
"Cook's Wonder"	12 in.		CS
Pine Bluff Sand & Grave	1 Co., P. O. Box 7008,	Pine Bluff 71601	
"Butcher"	24 in.	2200	CS
"Sand Hog"	10 in.	365	S
	CALIFORNIA		
Guy F. Atkinson Co., P.	O. Box 259, Long Beach	90801	
"4405"			ВС
"4410" "W= C"	10		BC
"Mr. Guy"	10 cu yd		ВС
Bohemia Inc., Umpqua Div	vision, 655 Skyway, Sui	te 118, San Carlos	94070

BC/BB BC BC

BC

20 cu yd 12 cu yd 7 cu yd

5 cu yd

"Oski" "Seal" "Beaver" "Mink"

DREDGE	OR BUCKET OR HOPPER CAPAC	CITY HORSEPOWER	TYPE
	CALIFORNIA (continued)		
	CALIFORNIA (continued)		
"Otter"	4 cu yd		ВС
"Fisher"	20 in./7 cu yd		S/BC
"Umpqua 9"	3000 cu yd		HB
"Umpqua 12"	4000 cu yd	·	HB
"Umpqua 14"	4000 cu yd		HB
"Umpqua 8"	3000 cu yd		НВ
Cressey Sand & Grave	el, Inc., 3495 N. Snelling Hw	y, Merced 953	40
"No. 1"	6 in.		CS
Dutra Dredging Co.,	1001 Murietta Blvd., P. O. H	Box 81, Livermor	e 94550
"California"	3 cu yd		ВС
"Liberty"	3 cu yd	Y	BC
"Sacramento"	2-3/4 cu yd		BC
"Alameda"	1-3/4 cu yd		BC
Graystone Block Co.,	316 River Road, Modesto 95	5351	
"No. 2"	6 in.		CS
Healy Tibbitts Const	ruction Co., 411 Brannan St.	, San Francisco	94107
"No. 11"	8 cu yd		BC/BG
"No. 3"	5 cu yd		BC/BG
"No. 7"	4 cu yd		BC/BG
"No. 43"	4 cu yd		BC/BG
R. R. Hensler, Inc.,	P. O. Box 547, Sun Valley	91352	
"Redondo"	12 in.	600	CS
Peter Kiewit Sons' 0	Co.; foot of So. 26th St., P.	0. Box 1512, R	ichmond
74002			
"Sandpiper"	16 in.		TH
"Trestle"	12 in.	M	CS
"Thelma"	15 cu yd		BC
"Cynthia"	4 cu yd		BC
"Jeanne"	3 cu yd		BC
"DS 10"	2000 cu yd		HB
"DS 11"	2000 cu yd		НВ

PIPELINE SIZE

PUMP

DREDGE

PIPELINE SIZE				PUMP	DREDGE	
OR	BUCKET	OR	HOPPER	CAPACITY	HORSEPOWER	TYPE

CALIFORNIA (continued)

DREDGE

Palo Verde Irrigation Dis	t., 180 W. 14th Ave., Blythe	92225						
"Palo Verde"	10 in.		CS					
San Francisco Port Commis	sion, Ferry Bldg., San Franci	isco 9411	1					
"No. 4"	4 cu yd	250	BC.					
Shellmaker, Inc., 250 Sears Pt. Rd., Petaluma 94952								
"Headway"	16 in.	3000	CC					
"Vanguard"	16 in.	2200	CS CS					
"Vagabond"		750	CS					
	12 in.							
"Traveler"	6 in.	150	S					
"Digger"	6 in.	150	S					
Smith-Rice Co., 2199 Clem	ent Ave., Alameda 94501	-450E3						
"Super Scoop"	15 cu yd	1700	ВС					
"No. 24"	6 cu yd	650	BC					
NO. 24	o eu yu	030	ьс					
U. S. Bureau of Reclamati P. O. Box 428, Needles 9	on, Lower Colorado River Pro 2363	ject Offic	e,					
"Little Colorado"	12 in.	900	CS					
"Gila"	12 in.	720	CS					
"Dredge"	10 in.	300	CS					
Dreage	10 111.	300	05					
Universal Dredging Corp., Oakland 94604	Div. Kaiser Engineers, 300 1	Lakeside D	rive,					
"Hydro-Pacific"	36 in.		CS					
"San Diego"	30 in.		CS					
"Explorer"	16 in.		CS					
Explorer	TO III.		00					
Western-Pacific Dredging	Corp., 135 Cutting Blvd., Ric	chmond 94	804					
"H.D. McCurdy"	26 in.		CS					
"John Franks"	26 in.		CS					
"Art Riedel, Sr."	20 in.		CS					
"Natoma"	20 in.		CS					
"Super Dredge"	30 in.		CS					
"Herb Andersen"	20 in.		CS					
mac our			-					

DREDGE	PIPELINE SIZE OR BUCKET OR HOPPER CAPAC	PUMP ITY HORSEPOWER	DREDGE TYPE
	CALIFORNIA (continued)		
"James H. Polhemus"	18 in.		CS
"Sandstorm 2"	16 in.		CS
"Sandstorm 1"	10 in.		CS
"Hercules"	5 cu yd		C
"Nitro"	5 cu yd		C
"D.B. Atlas"	4 cu yd		C
"Rockhound"	4 cu yd		С
"Samson"	4 cu yd		C
"Vulcan"	4 cu yd		C
"Titan"	4 cu yd		C
"Zeus"	4 cu yd		С
"D.B. Amazon"	3 cu yd		C
"Goliath"	3 cu yd		C
"Columbia"	2-1/2 cu yd		C
"Ajax"	2-1/2 cu yd		C
Yuba Gold Fields, Inc., Marysville 95901			
"Lisa"			BL
"17"			BL
Yuba River Sand Co., Inc., Box 307, Marysville 95901			
"No. 1"	8 in.		CS
	COLORADO		
Builders Aggregate Co., 329 E. 8th Ave., Fort Morgan 80701			
"No. 1"	8 in.	521238	S
Dye Construction, #4 Midland Road, Colorado Springs 80906			
"No. 2"	8 in.	350	CS
Mobile Premix Sand & Gravel, P. O. Box 5183 T.A., Denver 80217			
"No. 1"	12 in.	750	CS

CONNECTICUT

Essex Island Dock & Dredge, Inc., Ft. of Sunrise Ave., Old Saybrook 06475						
"Mallard I"	10 in.		CS			
Albert Jensen & Son, Denn	nison Road, Westbrook 06498					
"Mascot"	10 in.	600	CS			
"No. 16"	3/4 cu yd	100	BC/BG			
J. L. Spangle Marine Cons Norwalk 06851	struction Co., Inc., 28 West 1	Rocks Road,				
"Lynn"	1-1/4 cu yd	200	ВС			
Webb & Knapp Marine Corp.	, 1500 Elm St., Stratford Od	5075				
"Mike"	12 in.		CS			
"James E."	4 cu yd		BC			
	FLORIDA					
Capeletti Bros., Inc., P.	O. Box 4944, Hialieah 33014	4				
"Wanda C"	12 in.	375	CS			
"Kelly L"	16 in.	1200	CS			
E. I. DuPont de Nemours &	Co., Inc., P. O. Drawer A, I	Lawtey 320	58			
"No. 1"	20 in.	1000	CS			
"No. 2"	20 in.	1150	CS			
Hendry Corp., P. O. Box 13228, Tampa 33611						
"Hendry No. 5"	24 in.	5000	CS			
"Hendry No. 4"	24 in.	4800	CS			
"Hendry No. 2"	24 in.		CS			
"Hendry No. 6"	16 in.	2100	CS			
"HC-13"	4 cu yd		BC			
"HC-24"	24 in.	1800	BS			

DREDGE OF	PIPELINE SIZE R BUCKET OR HOPPER CAPA	PUMP ACITY HORSEPOWER	DREDGE TYPE
	FLORIDA (continued)		
Layne Dredging Co., P. O.	Box 1058, Gibsonton	33534	
"Michael L"	16 in.	2000	CS
"Robert M."			
"Miss Golden Isles"	12 in.	1000	CS
"Kings Bay"	12 in.	1000	CS
"Kelly L"	16 in.	1600	CS
"Cason"	29 in.	3200	CS
"H.B. Layne"	20 in.	3200	CS
M & M Dredging & Construc	ction Co., P. O. Box 54	47, Miami 33152	
"No. 11"	16 in.	oll out of Manual	CS
McHugh and Son Dredging (Contractors, 8791 64th	St. N., Pinnella	s
Park 33565	oneractors, or or oven	oc. m, rimeria	
"Kristi Karen"	12 in.	500	CS
"Shadow Run"	10 in.	400	CS
"Number 1"	10 in.	240	S
"Number 2"	8 in.	100	S
Parkhill-Goodlow Co., Inc	., P. O. Box 8707, Jac	cksonville 32211	
"Florida"	18 in.	3600	CS
"Dauntless"	18 in.	2600	CS
"XL"	18 in.	1500	CS
"AP No. 1"	10 in.	350	CS
"Booster Station No. 17"	18 in.	1800	BS
"Booster Station No. 48"	18 in.	1800	BS
"Booster Station"	14 in.	800	BS
Pillsbury Dredging Co., 1	Inc., Rt. 2, P. O. Box	430, Palmetto 3	3561
"Sand Piper"	12 in.	1250	CS
"Our No. 1"	8 in.	450	CS
our No. 1	o in.	450	0.5
Potashnick Construction 1	Inc., 303 S.E. 17th St.	., Fort Lauderdal	e 33316
"Rocky Ford"	24 in.	7350	CS
"Sait Louis"	24 in.	5600	CS
"No. 1"	16 in.	1500	CS
"No. 2"	12 in.	800	CS

DREDGE	PIPELINE SIZE DR BUCKET OR HOPPER CAPACITY	PUMP HORSEPOWER	DREDGE TYPE
	FLORIDA (continued)		
Prosperity Dredging Co.	, Inc., P. O. Box 12425, Lake	Park 33403	
"Palm Beach"	12 in.	500	CS
"Juno"	12 in.	560	CS
"Lake Park"	8 in.	500	S
St. George Island Gulf I	Beaches, Inc., P. O. Box 629,	Tallahassee	32302
"No. 1"	10 in.		CS
Shoreline Dredging & Con	nstruction Co., 33 Ashley St.	, Jacksonvil	le 32202
"Chesapeake IV"	12 in.	500	CS
"Chatham"	12 in.	350	CS
"Green Dragon"	10 in.	250	CS
	GEORGIA		
B. F. Diamond Constructi	ion Co., Inc., P. O. Box 727,	Savannah 3	1402
"Savannah"	18 in.		CS
Latex Construction Co.,	4959 New Peachtree Road, Atl	anta 30340	
"Natchez"	20 in.		CS
"Audrine"	12 in.		CS
	<u>HAWAII</u>		
Dillingham Overseas Corp	o., P. O. Box 3468, Honolulu	96801	
"Atlantic Warrior"	24 in.		CS
"L.S. Dillingham"	24 in.		CS
"Allan-Judith"	23 in.		CS
"Sam Houston"	20 in.		CS
"C.F. Weeber"	4 cu yd	1076	BC

IDAHO

Kloepfer Concrete Co., P. O. Box 87, Paul 83347

"No. 1"

8 in.

_

ILLINOIS

Allendale Gravel Co., R. F. D. No. 1, Allendale 62410

"Thomas HL"

-- S

Bull Towing Co., P. O. Box 888, Joliet 60434

"Bull Thrower"

16 in.

10 in.

400

S

Construction Aggregates, Corp., 120 South LaSalle St., Chicago 60603

"M/V Ezra Sensibar"	30 in.		HS
"American"	18 in.		HS
"Canadian"	36 in.		CS
"Ospwagan"	30 in.		CS
"Sensibar"	30 in.		CS
"Sensibar Son"	30 in.		CS
"Chimera"	27 in.		CS
"Bull Thrower"	12 in.		CS

DunBar Sand & Gravel Co., P. O. Box 97, Bellmont 62811

"No. 1"

8 in.

Fitz Simmons & Connell Dredge & Dock Div., Dunbar & Sullivan Dredging Co., 3025 E. 104th St., Chicago 60617

"Sioux"

5 cu yd

BC

S

Great Lakes Dredge & Dock Co., 228 North LaSalle Street, Chicago 60601

"Illinois"	27 i	n.	 CS
"Alaska"	27 i	n.	 CS
"New York"	27 i	n.	 CS
"Georgia"	26 i	n.	 CS

	PIPELINE SIZE	PUMP	DREDGE
DREDGE	OR BUCKET OR HOPPER CAPACITY	HORSEPOWER	TYPE
	ILLINOIS (continued)		
"Duplex"	25 in.	III	CS
"Rhode Island"	14 in.		CS
"Crest"	12 cu yd		BD
"Boston"	10 cu yd		BD
"Cleveland"	10 cu yd		BD
"Mogu1"	10 cu yd		BD
"No. 51"	9 - 15 cu yd		BC
"No. 52"	10 - 22 cu yd		BC
"No. 54"	10 - 22 cu yd		BC
	9 - 18 cu yd		BC
	9 - 18 cu yd		BC
"Conical"	6 - 12 cu yd		BC
"No. 50"	6 - 14 cu yd		BC
"No. 55"	5 - 12 cu yd		BC
"No. 56"	5 - 12 cu yd		BC
"No. 811"	4 - 6 cu yd		BC
La Crosse Dredging Cor	rp., 360 N. Michigan Ave., Chic	ago ·60601	
"Three Brothers"	22 in.	4000	CS
"Calumet"	20 in.	2200	CS
"Wilkinson"	18 in.	1750	CS
"Engler"	15 in.	1000	CS
"Mac Thompson"	15 in.	1000	CS
Lawder Sand Co., Grand	1 Tower 62942		
"No. 1"	10 in.		S
Luhr Bros. Inc., 1020	N. Main St., Columbia 62236		
"Elco"	20 in.		CS
McKenzie Dredging Co.,	Inc., P. O. Box 866, Galesbur	g 61401	
"Beaver"	14 in.	900	CS
"No. 781"	1 - 1/° cu yd	(8)	BC
"Iowa"	1 - 1/2 cu yd		BC
North American Trailin	ng Company Ltd., 360 N. Michiga	n, Chicago	60601
	reat Lakes & Dock Company, Amst		
Dredging Co., Amsterda			
"Manhattan Island"	3700 cu yd		TH

DREDGE	PIPELINE SIZE OR BUCKET OR HOPPER CAP	PUMP ACITY HORSEPOWER	DREDGI
	ILLINOIS (continued)		
Southern Illinois S	Sand Co., 1200 Swanwich St.,	Chester 62233	
"No. 3"	12 in.	600	S
"No. 2"	10 in.	150	S
	INDIANA		
Irving Gravel Co.,	Inc., 13415 Coldwater Road,	Ft. Wayne 46825	
"No. 1"	8 in.	400	CS
Knox County Sand Co	o., P. O. Box 524, Vincennes	47591	
"No. 1"	10 in.		S
Lafayette Waterwork	cs, 20 North 6th Street, Laf	ayette 47901	
"No. 1"	8 in.		S
	IOWA		
Acme Fuel & Materia	al Co., P. O. Box 34, Muscat	ine 52761	
"Lady Margaret"	10 in.	300	S
"No. 3"	10 in.	300	S
"No. 4" "No. 1"	8 in. 12 in.	250 350	CS S
Coots Materials Co.	, P. O. Box 90, Mt. Auburn	52313	
"Custom"	8 in.	335	S
Determann Blacktop,	, Inc., 1425 Washington Blvd	., Camanche 5723	0
"No. 1"	8 in.		CS
Moto Sand & Gravel	Co., 135 W. 5th St., Dubuqu	e 52001	
"No. 1"	10 in.	-	S

AD-A060 792

ARMY ENGINEER WATERWAYS EXPERIMEN" STATION VICKSBURG MISS F/G 6/6

A FEASIBILITY STUDY OF RESPONSE TECHNIQUES FOR DISCHARGES OF HA-ETC(U)

JUN 78 T D HAND, A W FORD, P G MALONE

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A FEASIBILITY STUDY OF RESPONSE TECHNIQUES FOR DISCHARGES OF HA-ETC(U)

JUN 78 T D HAND, A W FORD, P G MALONE

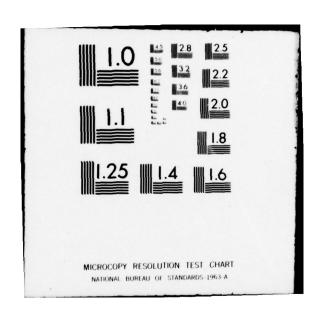
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DREDGE	PIPELINE SIZE OR BUCKET OR HOPPER CAPACIT	PUMP HORSEPOWER	DREDGE TYPE
	IOWA (continued)		
Perry Sand & Gravel Co.	, P. O. Box 345, Perry 502	220	
"No. 1"	6 in.		CS
West Des Moines Sand Co	., P. O. Box 98, West Des N	Moines 50265	
"No. 1"	10 in.	<u></u>	CS
Western Contracting Cor	p., 400 Benson Bldg., Sioux	c City 51101	
"Western Condor" "Western Chief" "WCC 501 Q"	42 i 30 in. 24 in.	34,000 13,000 3,200	CS CS BS
	KANSAS		
Barton County Highway D	Pept., P. O. Box 46, Great I	Bend 67530	
"No. 358" "No. 901" "No. 903"	8 in. 8 in. 8 in.	400 400 400	CS S S
Builders Sand Co., 78th	& Holliday Streets, Kansas	Gity 66106	
"No. 1"	8 in.		S
Martin K. Eby Construct	ion Co., Inc., P. O. Box 16	79, Wichita 6	7201
"Producer"	14 in.	1045	CS
Holliday Sand & Gravel	Co., 6811 West 63rd St., Ov	verland Park 6	6202
"Manhattan" "St. Joseph" "Liberty" "Edwardsville" "Bonner Springs"	12 in. 10 in. 10 in. 10 in. 8 in.	1000 450 450 400 300	CS CS CS CS
"Muncie"	8 in.	250	CS

1275

BL

"He1-De1"

OR BUCKET OR HOPPER CAPACITY HORSEPOWER

KANSAS (continued)

List & Clark Construction	Co., 6811 West 63rd St., Over1	and Park	66202
"Hawthron"	18 in.		CS
Miles Sand Co., Inc., 485	52 N. Meridian, Wichita 67204		
"No. 1"	10 in.		CS
Mueller Sand & Gravel Co.	, P. O. Box 396, Hanover 66945		
"No. 1"	8 in.		CS
Mulvane Sand Co., Inc., F	P. O. Box 4158, N. Wichita Sta.,	Wichita	67214
"No. 1"	10 in.		S
New Era Sand & Gravel Co.	, P. O. Box 843, St. Francis 6	7756	
"No. 1"	8 in.		S
"No. 2"	6 in.		S
Smith Sand Co., Inc., P.	O. Box 391, Garden City 67846		
"No. 1"	10 in.		S
"No. 2"	8 in.		S
OJ			
	V PAIDLIOUV		
60 m	KENTUCKY		
n			
J. F. Hardymon Co., P. O.	Box 628, Maysville 41056		
"Jeffco"	10 in.	(1993)	S
Henderson County Sand Co.	, P. O. Box 735, Henderson 424	20	

10 in.

Martin Marietta Aggregates, Central Division, Ohio River District, P. O. Box 1415, Louisville 40201

375 cu yd/hr

KENTUCKY (continued)

Aranahama	D4	01	c	C1	C-	Tma	D	^	Dans	1520	Oranghama	1.2201
Owensboro	Kiver	Sand	œ	Gravel	LO	Inc.	r.	U.	DOX	1330.	Owensboro	42301

"W. L. Delker"
"Emma D"

16 in.

S

10 in.

S

LOUISIANA

C. F. Bean Corporation, One Shell Square, Suite 3700, New Orleans 70139

"Jim Bean"	27 in.	16,000	CS
"Buster Bean"	27 in.		CS
"Lenel Bean"	27 in.		CS
"Blackburn"	27 in.	4,500	CS
"Dredge No. 32"	27 in.	4,500	CS
"Dredge No. 52"	27 in.	4,500	CS
"Shary"	27 in.		CS
"Holland"	24 in.	1,700	CS
"Borinquen"	22 in.		CS
"Kitty Bean"	20 in.		CS
"Dredge No. 85"	16 in.		CS
"Pipeliner"	12 in.		CS
"C. W. Bean"	8 cu yd		BG
"Bean No. 4"	5-1/2 cu yd		BG
"Bean No. 4"	6-1/2 cu yd		BG
"Bean No. 5"	6 cu yd		BG
"Bean 19"	27 in.		BS
"Bean 20"	27 in.		BS
"Bean 24"	27 in.		BS
"Nigeria"	20 in.	4	BS
"Booster 75"	20 in.		BS
"Booster 607"	27 in.		BS

International Dredging Inc., 19767 Chef Menteur Hwy., New Orleans 70129

"Gillespie"

20 in.

3,600

Freeport Sulphur Co., P. O. Box 61520, New Orleans 70106

"Ballard"

12 in.

LOUISIANA (continued)

Harvey Industries Inc.	, Peters Road, Harvey 70	058	
M/V "Kathy L"	20 in.	_2 100	S
Mike Hooks, Inc., P. C	D. Box 1525, Lake Charles	70601	
"Galveston"	24 in.		CS
"Louisiana"	24 in.		CS
"E. Stroud"	24 in.		CS
"Gavle"	20 in.	O Salting	CS
"No. 3000"	3 cu yd		BC
"No. 4000"	4 cu yd	<u></u>	BC
			The order
Dredging Division: P.	o. Box 826, Kenner 7006, Inc., P. 0. Box 56, Vid	2	
llm • II	20.	(000	-
"Tom James"	30 in.	6000	CS
"Capt. Clark"	30 in.	6000	CS
"Geo. D. Williams"	20 in.	3200	CS
"BT-51"	20 in.	2750	CS
"Lewis James"	26 in.	1600	CS
"Bobby James"	16 in.	1600	CS
"BT-57"	16 in.	800	S
"BT-10"	7 cu yd		BC
"Atlas No. 1"	6 cu yd	 , ;	BC
Lake Charles Dredging Lafayette 70505	& Towing Co., Inc., P. O.	Box 51554, O.C.	.s.,
"H. A. Sawyer"	22 in.		S
Marshland Dredging Co. 70808	, Inc., P. O. Box 14505,	S.E.Sta., Baton	Rouge
"Tennessee"	20 in.	NO. OF THE RESERVE AND ADDRESS.	CS
"Mr. Norman"	12 in.		CS
"No. 1"	8 in.		CS
"No. 3"	8 in.	TO SO HELDER	S
NO. 3	8 In.		3
J. Ray McDermott & Co.	, Inc., Drawer 38, Harvey	70058	
"Ralph T"	8 - 10 cu yd		BC/BG
"C. A. Beason"	8 cu yd		BC/BG
			,

DREDGE	PIPELINE SIZE OR BUCKET OR HOPPER CAPACITY	PUMP HORSEPOWER	DREDGE TYPE
	LOUISIANA (continued)		
"Creole"	8 cu yd		BC/BG
"Lafitte"	8 cu yd		BC/BG
"C. B. Dodgen"	6 cu yd		BC/BG
"M. B. Willey"	6 cu yd	esatiti es ati in	BC/BG
OKC Dredging, Inc. (Fo	rmerly Jahncke Service, Inc.),	P. O. Box 7	616,
"Fritz Jahncke"	27 in.	7700	CS
"Paul F. Jahncke"	24 in.	5500	CS
"Pontchartrain"	24 in.	5200	CS
"Manchac"	20 in.	2400	CS
"Congaree"	20 in.	2100	CS
"Booster No. 5"	27 in.	6000	BS
"Booster No. 3"	20 in.	1800	BS
Booster No. 3	20 111.	1000	В
P & L Hauling Construc	tion, Inc., U. S. Hwy 90, Bout	te 70039	
a) 4	12 in.	- 29	CS
Saba Dredging Co., Inc	., P. O. Box 363, Westwego 70	0094	
"Crown Point"	16 in.		S
"Titan"	14 in.		S
IILan	14 111.		
Standard Dredging Corp	., 6201 France Road, New Orles	ns 70126	
"New Jersey"	30 in.	6000	CS
"Windham"	27 in.	4000	CS
"Cartagena"	27 in.	4000	CS
"Orleans"	27 in.	4000	CS
"Cayman"	18 in.	2000	CS
Tidewater Dredging & C Metairie 70004	Construction Service, Inc., P.	O. Box 545,	
"Waldavick"	2 cu yd	- 3	ВС
Trinity Concrete Produ	cts Co., Drawer 790, Lake Char	rles 70601	
"No. 1"	16 in.		S
"No. 6"	12 in.		S
"No. 9"	12 in.		S
110.			

DREDGE	PIPELINE SIZE OR BUCKET OR HOPPER CAP	PUMP PACITY HORSEPOWER	DREDGI TYPE
	LOUISIANA (continued)		
"No. 8"	10 in.	<u></u>	S
"No. 4"	8 in.		S
Williams-McWilliams	Co., P. O. Box 52677, New	Orleans 70152	
"Diesel"	30 in.	8044	CS
"G. A. McWilliams"	28 in.	5650	CS
"Port Arthur"	24 in.	4640	CS
"Arkansas"	24 in.	4600	CS
"Natchez"	22 in.	4000	
			CS
"Vicksburg"	20 in.	2475	CS
	MAINE		
Northeast Dredging Co	o., Inc., 95 Florence St.,	South Portland	04106 CS
	MARYLAND		
Southern Maryland Dro 20758	edging, Inc., Woodside Far	m, Friendship, A.	A. Co.
"Finney Titus"	10 in.		CS
	MASSACHUSETTS		
Crosby & Scott, Inc.	, P. O. Box 456, Ostervill	e 02655	
"Seapuit"	10 in.	-	cs
Fournier Towing & Dre	edging Co., 134 Ten Hills	Road, Somerville	02143
"Detroit"	4 cu yd		ВС

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	PI	PEL	INE SIZI	E	PUMP	DREDGE	
OR	BUCKET	OR	HOPPER	CAPACITY	HORSEPOWER	TYPE	

MASSACHUSETTS (continued)

Hydro-Dredge Corp., P. O. Box 691, Falmouth 02540

DREDGE

"Sea Cologist"	12 in.		CS
"Sandpiper"	12 in.		CS
"Beatrice O"	10 in.		CS
"Evelyn T"	10 in.		CS
"Myles C"	5 cu yd		BC
"Sectional No. 1"	3 cu yd		BC
"Colombia Pt."	5 cu yd		BB
"Akron"	6 cu yd		BB
"Michael E"	5-1/2 cu yd		BB
"Big Ben"	3-1/2 cu yd		BB
"Cameron"	3 Tower	<u></u>	Dril1
			Boat
"James E"	2 Tower		Drill
			Boat

MICHIGAN

Buchman Bros., Marine Con	st., 30380 N. River Rd., Mt. C	Lemens	48043
"Edward A. Buchman"	1 cu yd		ВС
Bultema Dock & Dredge Co.	, 740 W. Western Ave., Muskegor	49440	38
"Michigan"	8 cu yd	-	BG
"Wisconsin"	6 cu yd		BG
"Illinois"	5 cu yd		BG
"Minnesota"	5 cu yd		BG
"Indiana"	3 cu yd		BG
"Ohio"	3 cu yd		BG
"Derrick No. C-1"	3 cu yd		BG
Dunbar & Sullivan Dredgin	g Co., 22720 Michigan Ave., Dea	rborn	48124
"Alabama"	22 in.	. r	CS
"Niagara"	22 in.		CS
"Dunbar II"	14 cu yd		BC
"Gotham"	6 cu yd		BC
"Ojibway"	5 cu yd		BC
"No. 4"	4-1/2 cu yd		BC

DREDGE	PIPELINE SIZE OR BUCKET OR HOPPER CAPACITY	PUMP HORSEPOWER	DREDGE TYPE
	MICHIGAN (continued)		
"No. 5"	3 cu yd		ВС
"Sullivan"	10 cu yd		BD
"Omadhoun"	9-1/2 cu yd		BD
"Empire"	7 cu yd		BD
Har-Bur Enterprises, In	c., 3860 U. S. 31, St. Joseph	49085	
"No. 1"	12 in.		CS
Luedtke Engineering Co.	, Frankfort 49635		
"No. 16"	8 cu yd		вс
"No. 14"	3-1/2 cu yd		ВС
"No. 12"	3-1/2 cu yd		BC
"No. 10"	3-1/2 cu yd		BC
"Weilston"	3-1/2 cu yd		BC
"No. 11"	3 cu yd		ВВ
Mead Brothers Excavatin	g Co., P. O. Box 99, Springpor	rt 49284	
"M & M"	12 in.		CS
John C. Meagher & Sons,	Inc., 1300 S. Water St., Bay	City 48706	
"Depere II"	3 cu yd		ВС
Michigan Dredging Co.,	Inc., P. O. Box 87, Hart 4942	20	
"Miss Mudhen II"	12 in.		cs
The Mucksuckers Inc., 1	15-1/2 E. Allegan St., Lansing	g 48933	
"Anchor Less"	14 in.	580	cs
New Hudson Sand & Grave	el Co., 4780 So. Hill Road, Nev	W Hudson 48	165
errection to the second	an and a final final first of the first of t	-	
Parker Construction Co.	. 7524 Lakeshore Road, Lexing	ton 48450	
"E. W. Parker"	8 in.	-	cs

PIPELINE SIZE			PUMP	DREDGE		
OR	BUCKET	OR	HOPPER	CAPACITY	HORSEPOWER	TYPE

MICHIGAN (continued)

DREDGE

	HICHIGAN (CONTINUEU)		
Shepard Marine Construction	on, 36900 Lamphier, Mt. Clemen	s 48043	
"No. 2"	1-1/4 cu yd		ВС
"Harris V"	3 cu yd		BC
"Barge 744"	2 cu yd		BC
Barge 744	z cu yu		ьс
Wm. W. Stender, Marine Con	ntractor, 1700 Evergreen Drive	, Bay Cit	у 48706
"Albert S."	12 in.	500	CS
"Alabama"	3-1/2 cu yd		BC
"Helen"	2 cu yd		BC
Wayne Sand & Gravel, Inc.	, P. O. Box 267, Wayne 48184		
"No. 1"	12 in.		CS
	MINNESOTA		
City of Albert Lea, Minn.	, Park Department, Albert Lea	56007	
"Foun-de-lea"	8 in.		S
Midwest Dredging Co., 573	O Duluth St., Minneapolis 554	22	
"Gopher"	18 in.	2000	CS
"M No. 3"	16 in.	1600	BS
"Andy"		1600	CS
"K-M No. 1"	3-1/2 cu yd		BS
"M No. 2"	3-1/2 cu yd		BS
City of Thief River Falls	, P. O. Box 528, Thief River Fa	alls 567	01
"No. 1"	8 in.	Luis es	CS
Winona Aggregate Co., Rt.	17, Winona 55987		
"Meckum"	14 in.		S

DREDGE	PIPELINE SIZE OR BUCKET OR HOPPER CAPACIT	PUMP Y HORSEPOWER	DREDGE TYPE			
	MINNESOTA (continued)					
Zenith Dredge Co., P.	O. Box 6568, Duluth 55806					
"Superior" "Duluth" "Adele"	luth" 5 cu yd					
	MISSISSIPPI					
Columbus Gravel Co F	. O. Box 2227, Columbus 397	01				
"No. 2"	10 in.		S			
"No. 1"	8 in.		S			
"No. 3"	8 in.		S			
	P. O. Box 220, Greenville	38701				
"Lee McCourt"	16 in.		S			
"Henry McCourt"	16 in.	- T	S			
St. Catherine Gravel C	Co., P. O. Box 928, Natchez	39120				
"St. Catherine"	16 in.	ell ha beleen	SD			
Stocker Sand & Gravel	Co., P. O. Box 176, Gnadenhu	tten 44629				
"Gravel Gerties"			CS			
"No. 2"	12 in.		CS			
	MICCOURT					
	MISSOURI					
Builders Sand Co., 78t	h & Holiday Streets, Kansas	City 66106				
"No. 1"	10 in.		CS			
"No. 2"	10 in.	-	CS			
Cape Girardeau Sand Co	., 1350 N. Water Street, Cap	e Girardeau	63701			
"No. 1"	14 in.	-	S			

	PIPELINE SIZE OR BUCKET OR HOPPER CAPACITY	PUMP	DREDGE		
DREDGE	HORSEPOWER	TYPE			
MISSOURI (continued)					
	MISSOOKI (CONTINUES)				
Glacial Sand & Gravel	Co., P. O. Box 36, Old Monroe	63369			
"No. 1"	8 in.		CS		
Bernard McMenamy Conti	ractor, Inc., 1600 Fair Lane, S	t. Charles	63301		
"Mc III"	24 in.		CS.		
"Mc IV"	20 in.		CS		
"St. Charles"	14 in.		CS		
	20 in.	1750	Booster		
Missouri State Park Bo	pard, 1204 Jefferson Building,	Jefferson Ci	ty 65101		
"No. 1"	8 in.		CS		
	NEBRASKA				
Einung Sand & Gravel (Co., P. O. Box 221, Wisner 687	91			
"No. 1"	10 in.	and orthogram	CS		
"No. 3"	10 in.		CS		
"No. 2"	8 in.		CS		
"No. 4"	8 in.		CS		
Hartford Sand & Gravel	Co., Valley 68064				
"No. 4"	14 x 16		CS		
"No. 5"	14 x 16		CS		
"No. 6"	14 x 14		CS		
"No. 7"	14 x 14		S		
"No. 1"	12 x 10		S		
"No. 2"	12 x 10 S				
"No. 3"	Lock Spall of	S			
NO. 3	10 x 8		3		
Missouri Valley Dredgi	ing Co., 1331 S. 20th Street, O	maha 68108			

CS CS

CS S S

18 in. 18 in. 18 in. 20 in. 12 in.

"Baldwin"
"Lynn"
"Wilbur J"
"Contikie"
"Boaz"

DREDGE	PIPELINE SIZE OR BUCKET OR HOPPER CAPACITY	PUMP HORSEPOWER	DREDG TYPE
	NEBRASKA (continued)		
Reigle Co., Brunswick	68720		
"Tom-Kat"	8 in.		S
Vlasak Sand & Gravel Co	o., 833 Norman, Crete 68333		
"No. 1"	8 - 10 in.		S
West Holt Gravel Co., A	Atkinson 68713		
"No. 1"	6 in.		S
	NEW JERSEY		
Barnegat Bay Dredging (Co., Inc., P. O. Box 336, Har	vey Cedars 0	8040
"Mike Thomas" "Reynold Thomas"	12 in. 12 in.	700 500	CS SB
	Inc., P. O. Box 100, Wenonah		
"Deep Water"	24 in.	4500	CS
"Clear Water"	14 in.	1000	CS
"J. W. Lyon"	10 cu yd		ВС
Gates Construction Corp	o., 208 Gates Road, Little Fe	rry 07643	
"Jonathon"	10 in.		CS
"Mary"	2 - 12 in.		S
"No. 302"	8 cu yd		BC
"No. 24"	5 cu yd		BC
"No. 196"	7 cu yd		BC
"No. 210"			S
Kummings Dredging Co.,	Cox Avenue, West Creek 0809	2	
"Transfer"	10 in.		CS
	Inc., 350 Riverside Avenue, R	utherford 07	070
The state of the s	The state of the s		
"No. 1"	8 in.		CS

DREDGE

		PI	PEL	INE SIZI	3	PUMP	DREDGE
DREDGE	OR	BUCKET	OR	HOPPER	CAPACITY	HORSEPOWER	TYPE

NEW JERSEY (continued)

South Jersey Concrete Pip	pe Co., Inc., P. O. Box 312, H	lammonton	08037
"No. 2"	12 in.		CS
"No. 1"	8 in.		CS
			Ob
Weeks Dredging & Contract	ing, Inc., 570 North Broad St	reet, Elia	zabeth 07208
"Weeks No. 500"	12 cu yd		BC
"Weeks No. 506"	12 cu yd		BC
"Weeks No. 505"	10 cu yd		BC
"Weeks No. 600"	6 cu yd		BC
Wenoah Sand & Gravel Co.,	P. O. Box 97, Gibbstown 082	07	
"No. 4"	8 in.		CS
	NEW YORK		
Concrete Materials, Inc.,	P. O. Box 64, Homer 13077		
"Candy"	12 in. x 14 in.	900	CS
"Booster No. 1"	12 in. x 14 in.	500	BS
Essex Marine Base, Inc.,	on Lake Champlain, Essex 129	36	
"LCjs"	3/8 cu yd	((o	BC
Gibson & Cushman Dredging	Corp., Inc., 38 Harman Ave.,	Bay Shore	11706
"No. 16"	20 in.	4400	CS
"No. 14"	16 in.	2000	CS
"No. 15"	16 in.	1700	CS
"No. 8"	16 in.	1000	CS
"Sninnecock"	12 in.	1200	CS
New York State Dept. of 1 12226	Transportation, 1220 Washingto	n Ave., Al	bany
"No. 4"	15 in.	750	CS
"No. 3"	15 in.	500	CS
'No. 5"	15 in.	448	CS
NO. 3	IJ III.	440	U.S

DREDGE	PIPELINE SIZE OR BUCKET OR HOPPER CAPACI	PUMP HORSEPOWER	DREDGE TYPE
	NEW YORK (continued)		
"No. 1"	12 in.	175	CS
"No. 4"	1-1/2 cu yd	153	BC
"No. 6"	1-1/2 cu yd	153	BC
"No. 13"	1-1/2 cu yd	105	BC
"No. 8"	1-1/4 cu yd	100	BC
"No. 1"	1-1/4 cu yd	75	BC
"No. 2"	1-1/4 cu yd	80	BC
"No. 2A"	1-1/4 cu yd	100	BC
"Wards Island"	1 cu yd	500	BC
"No. 3"	3-1/4 cu yd	175	BD
"Grandall No. 1"	1 cu yd	200	ВВ
"Grandall No. 4"	1 cu yd	200	ВВ
South Shore Dredgin	ng Co., Inc., 501 Grove Ave., I	Patchogue 1177	2
"Smithtown"	16 in.	1700	CS
"Southampton"	12 in.	800	CS
"Brookhaven"	12 in.	800	CS
"Islip"	12 in.	800	CS
Suffolk Dredging, S	Shore Road, Port Washington 1	1050	
"Suffolk"	22 in.		SH
"Riverhead"	10 in.		S
Rivernead	10 III.		
	NORTH CAROLINA		
	2 to track the district of the second		
Gene Caudill Constr	ruction Co., P. O. Box 1087, N	. Wilkesboro 2	8659
"No. 1"	8 in.	-	CS
28303	Gravel Co., Inc., P. O. Box	5632, Feyettevi	lle
'No. 1"	14 in.		CS
Gilbert Dredging Co	o., 509 W. Ehringhaus Street,	Elizabeth City	27909
"Beaver"	12 in.		CS
"Mink"	8 in.		S
The state of the s			

DREDGE		NE SIZE HOPPER CAPACITY	PUMP HORSEPOWER	DREDGE TYPE
	NORTH CAROLINA	(continued)		
North Carolina State 1	Highway Commiss	lon, Mann's Harb	or 27953	
"Carolina" "Buxton"	12 in. 8 in.	442 - 15 500 - 15 - 15	1350 575	CS CS
	OUT	8 X88 4, Q-18 , Let		
	OHIC	10.10		
Ajax Company, Marine I	Building, 1284 N	Miller Road, Avo	n 44011	
"Great Lakes"	24 in.		37790	CS
"Amy A"	16 in.			CS
"Four Sons"	12 in.			CS
"Erie"	8 in.			CS
"Carterett"	800 tons			TH
"No. 4"	24 in.		1800	Booster
"No. 5"	14 in.		600	Booster
"No. 6"	10 in.		250	Booster
"Ajax Challenger"	5 cu yd			BC
"E 17"	205 ft x 44	ft x 14 ft		Spud Barge
Allied Dredging Co., I	P. O. Box 490, I	t. Clinton 434	52	
"Seneca"				nc.
"J. C."	3 cu yd			BC BC
J. C.	1/2 cu yd		·	ВС
Capital Dredge & Dock	Corp., P. O. Bo	x 550, Lorain	44052	
"Moran"	18 in.	a unit:	CHAPTER 11	CS
"Myrna-L"	18 in.		trought a pho	CS
"Michele"	14 in.	of the street of	and s ome different	CS
Grant Contracting Co.	, Drawer 160, Gr	eenville 45331		
"America"	22 in.		4000	CS
"Columbus"	18 in.	THE PLANE	3000	CS
Hess-Von Bulow, Inc.,	4017 Nanway Blv	d., Ravenna 44	266	
"No. 1"	6 in.	THE RESERVE	and find of the little	CS
"Colleen"	6 in.	Service of		CS CALL

DREDGE OF	PIPELINE SIZE BUCKET OR HOPPER CAPACITY	PUMP HORSEPOWER	DREDGE TYPE
	OHIO (continued)		
Fred Price Contracting Co	., P. O. Box 5, Chesterhill	43728	
"No. 1" "No. 2"	8 in. 2 cu yd	420	CS BC
Price Sand & Gravel Co.,	P. O. Box 445, Norwalk		
"Ammoco"	8 in.		CS
Stocker Sand & Gravel Co.	, P. O. Box 176, Gnadenhutte	en 44629	
"Gravel Gerties" "No. 2"	 12 in.	Ξ	CS CS
	OKLAHOMA		
Mohawk Rock & Sand Co., I	P. O. Box 640, Sand Springs	74063	
"No. 1"	150 cu yd		CS
"No. 2"	150 cu yd		CS
"No. 3"	150 cu yd	and the latest	CS
"No. 4"	60 cu yd		CS
Oklahoma Dredging Co., P.	0. Box 10, Poteau 74953		
"Oklahoma"	16 in.	1480	CS
"ODC 701"	16 in.	1835	BS
Yahola Sand & Gravel Co. (Div. of Arkhola S & G Co	P. O. Box 1401, Muskogee	74401	
"Yahhola No. 1"	8 in.	20 ji 1816	CS
	OREGON		
Bohemia Inc., Umpqua Div	ision, 2280 Oakmont Way, Eug	ene 97401	
"Oski"	20 cu yd		BC/BB
"Seal"	12 cu yd	-	ВС

DREDGE OF	PIPELINE SIZE BUCKET OR HOPPER CAPACITY	PUMP HORSEPOWER	DREDGE TYPE
	OREGON (continued)		
"Beaver"	7 cu yd		ВС
"Mink"	5 cu yd		BC
"Otter"	4 cu yd		BC
"Fisher"	20 in./7 cu yd		S/BC
"Umpqua 9"	3000 cu yd		НВ
"Umpqua 12"	4000 cu yd		НВ
"Umpqua 14"	4000 cu yd		НВ
"Umpqua 8"	3000 cu yd	-	НВ
General Construction Co.,	P. O. Box 10346, Portland	97210	
"Papoose"	30 in.	4500	CS
"Washington"	24 in.	3600	CS
"Missouri"	24 in.	3000	CS
"Mac Leod"	24 in.	2500	CS
"Sandra Lee"	16 in.	900	CS
"The Dalles"	5 cu yd	450	BC
"G. C. 32"	5 cu yd	450	BC
"Barrard"	4 cu yd	335	BC
"Beaver"	3 cu yd	250	BC
"G. C. 34"	3 cu yd	250	BC
"H & M"	3 cu yd	250	BC
"Portland"	3 cu yd	250	BC
rortiand	5 cu yu	230	ьс
Hayden Island, Inc., High	way 5 at Jantzen Beach, Por	tland 97217	
-	8 in.	475	S
Palmberg Construction Co.	, P. O. Box 448, Warrenton	97146	
"Alaska"	12 in.	450	CS
"Hydro"	12 in.	450	CS
"Mole"	12 in.	450	CS
"Oregon"	30 in.	8950	CS
Western-Pacific Dredging Portland 97203	Corp., Foot of North Portsm	outh Avenue,	
"H. D. McCurdy"	26 in.		CS
"John Franks"	26 in.		CS
"Art Riedel, Sr."	20 in.		CS
"Natoma"	20 in.		CS
"Super Dredge"	30 in.		CS
Super Dreage	50 III.		CO .

	PIPELINE SIZE	PUMP	DREDGE
DREDGE	OR BUCKET OR HOPPER CAPACITY	HORSEPOWER	TYPE
	OPPON (1)		
	OREGON (continued)		
"Herb Andersen"	20 in.		CS
"James H. Polhemus" "Sandstorm 2"	18 in. 16 in.		CS
"Sandstorm 1"	10 in.		CS CS
"Hercules"	5 cu yd		C
"Nitro"	5 cu yd		C
"D. B. Atlas"	4 cu yd		C
"Rockhound"	4 cu yd		C
"Samson"	4 cu yd		C
"Vulcan"	4 cu yd		C
"Titan"	4 cu yd	0 6 13 5 3 7 7 7 7	C
"Zeus"	4 cu yd		C
"D. B. Amazon"	3 cu yd		C
"Goliath"	3 cu yd		C
"Columbia"	2-1/2 cu yd		C
"Ajax"	2-1/2 cu yd		C
	PENNSYLVANIA		
Amenda an Davidada a Ga	10 C 10-1 C- D	14- 10107	
American bredging Co.,	12 South 12th St., Philadelp	hia 19107	
"American"	27 in.		CS
"Arkansas"	27 in.		CS
"Ozark"	27 in.		CS
"Maryland"	16 in.		CS
"Convoy"			BG
"Titan"			BC
"President"			BD
Garden Brooklessen Torri	100 5 0 0	1.1 151/2	
Crain Brothers, Inc.,	122 East Beaver Street, Sewic	kley 15143	
"No. 5"	4 cu yd		ВС
"No. 3"	2-1/2 cu yd		BC
"No. 4"	2-1/2 cu yd		BC
"No. 8"	2-1/2 cu yd		BC
"No. 9"	2-1/2 cu yd	AutomotA	BC
"No. 1"	4 cu yd		BC
"No. 2"	2 cu yd		BC
	tern Construction Division, N	eville Island	,
Pittsburgh 15225			
Un			00
"Dravo 65"	14 in.		CS

DREDGE	PIPELINE SIZE OR BUCKET OR HOPPER CAPACITY	PUMP HORSEPOWER	DREDGE TYPE
	DENNICYI VANTA (continued)		
	PENNSYLVANIA (continued)		
"No. 9"	1-1/2 cu yd		ВС
"No. 10"	1-1/2 cu yd		BC
"No. 11"	1-1/2 cu yd		BC
"No. 12"	1-1/2 cu yd		BC
"No. 13"	1-1/2 cu yd		BC
"No. 14"	1-1/2 cu yd		BC
"No. 15"	1-1/2 cu yd		BC
"No. 16"	1-1/2 cu yd		BC
"No. 17"	1-1/2 cu yd		BC
"No. 18"	1-1/2 cu yd		BC
"No. 19"	1-1/2 cu yd		BC
"No. 21"	3/4 cu yd		BC
"No. 22"	2-1/2 cu yd		BC
"No. 23"	4 - 7 cu yd		BC
"No. 24"	4 cu yd		BC
"No. 25"	5/8 cu yd		BC
"No. 26"	5/8 cu yd		BC
"No. 27"	3-1/2 cu yd		BC
East Coast Dredging, In Philadelphia 19147	nc., P. O. Box 18068, Southwar	k Station,	
"Jamie"	14 in.		CS
Eastern Seaboard Pile I Philadelphia 19147	Oriving, Inc., P. O. Box 18099	, Southwark	Station,
"Beverly M"			CS
"Draga-De-Arena"			
Erie Sand & Gravel Co., Erie 16512	Esco Dredge & Fill Division,	P. O. Box 1	53,
"J. S. St. John"	600 cu yd		S
Monongahela and Ohio Dr McKees Rocks 15136	edging Co., Ohio River at Ohi	o Street,	
"Beaver"	4 cu yd		BD
"Northern"	3-1/2 cu yd		BD
"Kanawha"	2-1/4 cu yd		BD
"Pacific"	2 cu yd		BD
"Modco"	3-1/2 cu yd		ВС

DREDGE	PIPELINE SIZE OR BUCKET OR HOPPER CAPACITY	PUMP HORSEPOWER	DREDGE TYPE
	PENNSYLVANIA (continued)		
"No. 2" "Ohio"	3 cu yd 3 cu yd	<u></u>	BC BC
Onio	3 eu yu		ьс
Oil City Sand & Gravel	Co., 726 W. Front Street, 01	1 City 16302	
"No. 2"	1-1/2 cu yd		BD
"Warren"	1-1/2 cu yd		BD
"Oil City"	1-1/4 cu yd		BC
	SOUTH CAROLINA		
Coastal Sand Co., P. O	Box 305, Johnsonville 2955	5	
"Barbara"	6 in.		S
"Ann"	6 in.	-	S
Merritt Dredging Co.,	P. O. Box 3288, Charleston 2	9407	
"Clinton"	18 in.		CS
"Cherokee"	18 in.		CS
"Junaluska"	14 in.		CS
Plowden Construction C	Co., Inc., P. O. Box 129, Sumt	er 29150	
"Admiral"	12 in.		CS
Salmons Dredging Corp.	, P. O. Box 42, Charleston 2	9402	
"Capt. Harry"	200 T lift		S
"Little Boss"	100 T 11ft	-	S
	TENNESSEE		
Central States Dredgin	g Co., P. O. Box 16806, Memph	is 38116	
"Robert H"	12 in.		S
"Diana G."	10 in.		S
"Sylvia G."	8 in.	-	S

DREDGE	PIPELINE SIZE OR BUCKET OR HOPPER CA	PUMP APACITY HORSEPOWER	DREDGE TYPE
	TENNESSEE (continued	<u>i)</u>	
Dixie Sand & Gravel C	Co., 515 River Street, Cl	nattanooga 37402	
"Richard Hardy"	300 tons/hr		BL
"No. 8"	500 tons/hr		BL
H. D. Wilder Company,	582 North 2nd Street, M	Memphis 38105	
"Keystone"	12 in.		CS
"Memphis"	12 in.		CS
"Walls"	10 in.		CS
	TEXAS		
Deshotel Boat Service	, 5046 6th Street, Port	Arthur 77640	
"Sea Shell"	12 in.		CS
"Keystone"	12 in.		CS
Garrett Construction	Co., P. O. Box 9257, Con	pus Christi 78408	
"Padre Island"	15 in.	n, treed galajorit it	CS
"Melvin"	12 in.		CS
King Fisher Marine Se	rvice, Inc., P. O. Box	108, Port Lauaca 7	7979
"Caamaa E "	16.4-		CC
"George F." "Sand Fiddler"	16 in. 12 in.	Company of the same of the same	CS CS
bund Trudrer	12 111.		00
Horton & Horton, Inc.	, P. O. Box 1669, Housto	on 77001	
"Leonard M. Fisher"	20 in.	2000	CS
"Everett Fisher"	18 in.	2000	CS
"Shamrock"	12 in.	1000	CS
"Mighty Mite"	12 in.	600	CS
"Tyro Jr."	12 in.	450	CS
"Katrina II"	2-1/2 cu yd	-	BC
Loyd W. Richardson Co Pass 78336	nstruction Corp., 1054 S	S. Rite Street, Ara	nsas
"Tiger"	16 in.	1600	CS

	PIPELINE SIZE	PUMP	DREDGE
DREDGE OF	R BUCKET OR HOPPER CAPACITY	HORSEPOWER	TYPE
	TEXAS (continued)		
"Loyd W. Richardson"	12 in.	1000	CS
"Archie"	10 in.	300	CS
Service Marine Co., Inc.,	P. O. Box 627, Galena Park	77547	
"Armadillo II"	20 in.	rimagno <u>.</u> Table	CS
"GG II"	2-1/2 cu yd		BC
	VIDCINIA		
	VIRGINIA		
	0 P 1500/ Olesses 1	2222	
Atkinson Dredging Co., P.	0. Box 15284, Chesapeake	23320	
"Enterprise"	18 in.		CS
"Hampton Roads"	18 in.		CS
"Northwood"	16 in.		CS
"Booster No. 1"	18 in.		BS
"Booster Barge No. 1"	18 in.		BS
"Booster Barge No. 2"	18 in.		BS
Chesapeake Dredging Corp.	, P. O. Box 13246, Chesapea	ke 23519	
u	1/ /-		CC
"Virginia Beach"	14 in.		CS
"Chesapeake"	12 in.	a temperatura	CS CS
"Little Ive"	8 in.		CS
Cottrell Engineering Corp	o., 541 Front Street, Norfol	k 23510	
"Richmond"	12 in.	1000	CS
"Marion"	12 in.	1000	CS
"Neuse"	12 in.	800	CS
"Blue Ridge"	12 in.	500	CS
Norfolk Dredging Co., P.	0. Box 539, Norfolk 23501		
"Pullen"	22 in.	5000	CS
"Talcott"	18 in.	2900	CS
"Stuart"	18 in.	2500	CS
"No. 44"	16 in.	1450	CS
"Jekyll Island"	14 in.	1150	CS
"The Virginian"	16 cu yd	900	BC
"Perry"	6 cu yd	250	BC
"Philos"	3 cu yd	250	ВС

PUMP OR BUCKET OR HOPPER CAPACITY HORSEPOWER

DREDGE TYPE

WASHINGTON

American Construction Co.	, Inc., 411-13th Street, Ever	ett 98201	
"Mukilteo"	5 cu yd	700	ВС
"Snohomish"	3 cu yd	550	BC
Evergreen Tug & Barge Co.	, Route 1, P. O. Box 40, Mary	sville 98	270
"Seacrest No. 1"	4 in.	120	CS
"Seacrest No. 2"	1/2 cu yd	120	BC
Hadco Dredging Co., 1429	S. Meridian, Puyallup 98371		
"Hadco No. 1"	10 in.	-	CS
Harbor Rock, Inc., P. O.	Box 246, South Bend 98586		
"Forest No. 8"	1 cu yd	-	ВС
Leiter Hockett, Divers & Seattle 98107	Subaqueous Engineering, 3415	N.W. 66th,	
"No. 1"			ВС
Manson-Osberg Co., 1132 N	o. 128th St., Seattle 98133		
"Husky"	20 in.	4000	CS
"Malamute"	16 in.	1500	CS
Marine Construction & Dre 98273	dging, Inc., Route 1, P. O. B	ox 6, Mt.	Vernon
"Skagit Bay"	14 in.	1375	CS
"Shrimp"	8 in.	318	CS
Port of Bellingham, 625 C	ornwall Avenue, Bellingham 9	8225	
"No. 1"	1-1/2 cu yd	-	BC/BG
Quigg Brothers-McDonald,	Inc., P. O. Box 1707, Aberdee	n 98520	
"Hoquiam"	12 in.	500	S
"Melbourne"	12 in.	500	S
"Monarch"	4 cu yd	-	ВС

	PIPELINE SIZE	PUMP	DREDGE
DREDGE	OR BUCKET OR HOPPER CAPAC	HORSEPOWER	TYPE
	WASHINGTON (continued)		
Twin Harbors Dredging	Co., P. O. Box 1707, Aberd	een 98520	
"Hoquiam"	12 in.	500	S
"Melbourne"	12 in.	500	S
"Monarch"	4 cu yd		BC
	ing Corp., P. O. Box 3007, ing Corp., P. O. Box 2160,		
(See Oregon Listing)			
	WEST VIRGINIA		
Ohio River Sand & Grav Parkersburg 26101	vel, Division of McDonough	Co., P. O. Box	538,
"Joe Lucas"	16 in.	2000	CS
"West Virginia"	14 in.	1300	CS
	WISCONSIN		
McMullen & Pitz Const	ruction Co., P. O. Box 8, M	Manitowoc 54220	
"No. 39"	2 cu yd		ВС
"No. 40"	2 cu yd	<u></u> -	BC
"No. 46"	1-1/2 cu yd		BC
"No. 64"	1-1/2 cu yd		ВС
Robers Dredge, Inc.,	816 S. Bainbridge Street, I	a Crosse 54601	
"Louise"	16 in.	2240	CS
"Marikaye"	3 cu yd	450	BC
"Hydraulic"	16 in.	1080	BS

OR BUCKET OR HOPPER CAPACITY HORSEPOWER

UNITED STATES ARMY CORPS OF ENGINEERS DREDGES

U. S. Army Engineer Dist 99510	rict, Alaska, P. O. Box 7002	, Anchorage, Alaska					
"Dillingham"	10 in.	365 CS					
"Gilpin"	3/4 cu yd	131 BC					
U. S. Army Engineer Dist New York 14207	rict, Buffalo, 1776 Niagara	Street, Buffalo,					
"Hoffman"	920 cu yd	1,810 TH					
"Lyman"	920 cu yd	1,810 TH					
"Markham"	2680 cu yd	7,300 TH					
U. S. Army Engineer District, Chicago, 219 S. Dearborn Street, Chicago, Illinois 60604							
"Depoe Bay"	8 in.	165 CS					
"Kewaunee"	6 cu yd	150 BD					
"Winneconne"	2-1/2 cu yd	100 BC					
U. S. Army Engineer District, Detroit, P. O. Box 1027, Detroit, Michigan 48231							
"Hains"	885 cu yd	1,810 TH					
"Tompkins"	2 or 3 cu yd	100 BC					
U. S. Army Engineer District, Galveston, P. O. Box 1229, Galveston, Texas 77553							
"McFarland"	3140 cu yd	11,600 ТН					
U. S. Army Engineer District, Jacksonville, P. O. Box 4970, Jacksonville, Florida 32201							
"Davison"	720 cu yd	1,810 TH					
"Gerig"	3060 cu yd	8,300 TH					
"Hyde"	720 cu yd	1,810 TH					
U. S. Army Engineer District, Kansas City, 700 Federal Building, Kansas City, Missouri 64106							
"Black"	34 in.	2,900 SD					

UNITED STATES ARMY CORPS OF ENGINEERS DREDGES

(continued)

"Mitchell"	34 in.	2,900	SD				
"Lewis"	34 in.	2,900	SD				
U. S. Army Engineer Dis Building, Memphis, Tenn		Clifford Davis Feder	cal				
"Burgess"	32 in.	4,000	SD				
"Ockerson"	32 in.	3,200	SD				
"Potter"	32 in.	3,050	SD				
U. S. Army Engineer Dis 36628	trict, Mobile, P. O.	Box 2288, Mobile, A	Alabama				
"Collins"	20 in.	2,600	CS				
"Guthrie"	16 in.	1,275	CS				
U. S. Army Engineer Dis Louisiana 70160	trict, New Orleans, F	P. O. Box 60267, New	orleans,				
"Langfitt"	3060 cu yd	8,300	TH				
U. S. Army Engineer District, Omaha, 6014 USPO & Courthouse, 215 North 17th Street, Omaha, Nebraska 68102							
"Henderson"	8 in.	335	CS				
U. S. Army Engineer Dis Chestnut Street, Philad			, 2nd &				
"Comber"	3524 cu yd	8,300	TH				
"Essayons"	8115 cu yd	11,700	TH				
"Goethals"	6361 cu yd	7,100	TH				
"Fry"	12 in.	1,180	S				
U. S. Army Engineer Dis Oregon 97208	strict, Portland, P. C		ıd,				
"Biddle"	3060 cu yd	8,300	TH				
"Harding"	2720 cu yd	6,240	TH				
"Pacific"	500 cu yd	1,540	TH				
"Luckiamute"	12 in.	750	CS				

	PIPELINE SIZE				PUMP	DREDGE	
REDGE	OR	BUCKET	OR	HOPPER	CAPACITY	HORSEPOWER	TYPE

UNITED STATES ARMY CORPS OF ENGINEERS DREDGES (continued)

DR

"Merritt"

"Multnomah" 24 in. 1,000 CS "Walkiakum" CS 24 in. 3,500 U. S. Army Engineer District, St. Louis, 210 North 12th Street, St. Louis, Missouri 63101 "Ste. Genevieve" 20 in. 2,200 CS "Kennedy" 24 in. 2,200 SD U. S. Army Engineer District, St. Paul, 1135 USPO & Custom House, St. Paul, Minnesota 55101 "Thompson" CS 20 in. 2,800 "Gaillard" 6 cu yd 550 BD U. S. Army Engineer District, Vicksburg, P. O. Box 60, Vicksburg, Mississippi 39180 "Dredge-6" 8 in. 110 CS "Jadwin" 32 in. 4,300 SD U. S. Army Engineer District, Wilmington, P. O. Box 1890, Wilmington, North Carolina 28401 "Schweizer" 16 in. 1,150 S

1,180

S

12 in.

APPENDIX D: LITERATURE REVIEW OF BURIAL AND BURIAL MATERIALS

Early work on the effectiveness of covers was conducted in Sweden. Jernelov 34 found that in a system without macroorganisms, release of methyl mercury occurs almost entirely in the upper centimeter of the sediment. Thus, in this situation, natural sedimentation must be an important factor for turnover of mercury deposits in the sediment. The presence of <u>Tubificidae</u> in very high amounts changes the situation somewhat, but it still is the mercury deposits in the upper 2.5 cm of the sediment that give the dominating contribution to the formation and release of methyl mercury. When <u>Anodonta</u> (mussels) are present—with a very high population density—the depth at which deposits of inorganic mercury contribute is expanded to about 9 cm.

The fact that both <u>Tubificidae</u> and <u>Anodonta</u> tend to expand the active depth of the sediment according to their length and to the depth in the sediment they reach and mix supports the idea that they influence the release of methyl mercury from the sediment mainly through physical activity—mixing sediment and increasing the flow-through of water. This makes the population density an important factor. If this physical mechanism for release is dominant, then it can be expected to apply similarly to other sediment—bound contaminants.

It appears to be possible to "lock in" the mercury in the sediment by a covering layer of 3 cm if there were no macroorganisms or only Tubificidae present. But if Anodonta are present, a covering layer of 10 cm would be required. These examples illustrate the need to consider, for each spill situation, the likely benthic activity on and in the materials being considered as covers.

Landner 89 investigated ways to restore polluted lakes in Sweden and concluded that several approaches are possible. These include:

- o Introducing materials with strong adsorption characteristics to fix the contaminants in a less mobile form, or
- o Covering with an inorganic material.

He used an 0.5- to 1-mm-thick layer of lime to cover fibrous sediments

polluted with phenyl mercury and found that this reduced the available mercury by a factor of 5. A similar experiment was conducted using silicate minerals as a cover and a significant reduction in the available methyl mercury was found. Less effectiveness was attained in the case of phenyl mercury.

Landner ⁸⁹ also conducted tests in lakes, where freshly ground quartz mineral was spread over the bottom to attempt to seal in-place methyl mercury. The results obtained were inconclusive because of the difficulties associated with obtaining a uniform layer on the bottom. Due to a shortage of funds, the quartz was barged to the site and then spread with hand shovels. Large patches of the bottom remained exposed using this method.

EPA has funded a number of projects to evaluate the effectiveness of bottom covers and, while these have also been directed toward heavy metals problems, the results are of interest to other in-place pollutants as well.

Feick, Johanson, and Yeaple conducted aquarium studies with organic and inorganic mercury and evaluated the effectiveness of several covering materials (sand, kaolin clay, silica, zinc sulfide, milled pyrite, thiols, and polyethylene). Tests were also conducted on combinations of these (i.e., a chemical complexing agent below a sand barrier). They found that oxidizing of the polluted sediments resulted in increased availability to the ecosystem, hence the desirability of a "blanket" or cover to keep the sediment anaerobic. Plastic films (polyethylene) did not appear to be an effective barrier for sealing against methyl mercury. In dredging simulation, they found that about 99 percent of the mercury present remained bound to particulate matter. This implies that dispersion and resuspension should be avoided to control the spread of the pollutant.

Bongers and Khattak 90 investigated the effectiveness of sand and gravel as a cover for mercury-contaminated sediments. The release of toxic mercurials by mercury-enriched river sediments was examined in the laboratory. These tests indicated that about 1 μ g of methyl mercury was released per square meter per day. The release of such toxic

mercurials could be prevented by a layer of sand, 6 cm in thickness, applied over the mercury-enriched sediments. Layers of fine or coarse gravel (6 cm deep) were as effective as sand. Thinner layers of sand, 1.5 and 3 cm in thickness, appeared to be unsatisfactory. The cost of applying 3-in. layers of sand or gravel over contaminated river sediments was estimated to be about \$3000 to \$4000 per acre.

Although the laboratory investigations proved the soundness of the sand blanket approach, its practical and economic feasibility must be determined in a combined field and laboratory analysis program.

Saila⁴⁰ has investigated the effectiveness of covers for material in Rhode Island Sound, including stability associated with material that is in a mound. Gordon⁹¹ indicates that stability can be enhanced in some cases by actively cultivating a biological population such as tubedwelling polychaetes.

Pratt and O'Connor³⁵ have considered the problem of providing a cover over polluted dredged material in a disposal site. They felt that the cover need not be totally sealed, at least in the case of the moderately contaminated sediments of their study. In that case they stated that a cover should be judged successful if it reduces the exposed surface area by 90 to 95 percent and provides a blanket thick enough to keep the dominant benthic species from contact with the contaminated material. A practical consideration was that only unconsolidated sediments can be spread evenly enough to cover a large area, so that although clay material would be desirable in a cover due to its adsorptive capacity, spreading of a cover containing significant amounts of consolidated clay may not be practicable.

Work performed for the Canadian Department of the Environment 18 has directly addressed the use of covering as a technique for reducing contamination of the water column due to polluted sediments. In situ treatment methods discussed included the use of both inert and chemically active covering layers. Required depths of burial were not thought to be large, phosphorus desorption being reported to take place in the top 14 mm of sediments. Bottom stability was singled out as perhaps the most important factor limiting the use of covering layers,

and a two-layer approach using a coarse-grained material over a fine-grained cover was suggested to combat this.

Covering strategies dictate the materials to be considered for use. Obviously, simple covering using an inert bottom layer, such as was done by Jernelov³⁴ and tested by Bongers and Khattak,⁹⁰ is a possibility. The use of active covering materials to neutralize or decrease toxicity of the spilled chemical has also been suggested in early work. These might require covering with an inert material to retard erosion, but would generally constitute a cover in and of themselves. The use of chemical additives to an inert covering material is a possibility. Finally, sealing and grouting methods (in-place cementation, polymer films, etc.) could be used to retard leaching or fix sediment in place. It is possible that these could be used in conjunction with any of the other emplacement strategies (e.g., additives to the concrete, inert cover over a polymer film, etc.).

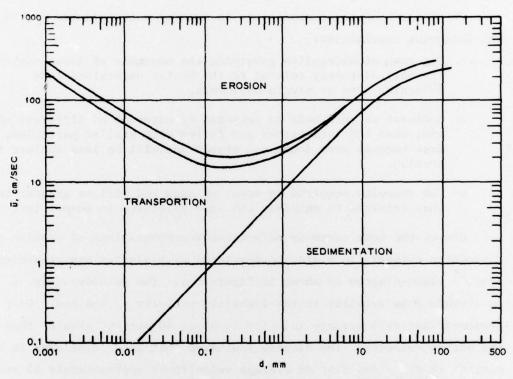
APPENDIX E: SCOUR AND RESUSPENSION OF NATURAL SEDIMENTS--A DETAILED DISCUSSION

Erosion and resuspension of noncohesive sediment is an important consideration for covering a spilled substance with a coarse-grained layer to minimize leaching of pollutants. Much of the following discussion follows the presentation of Graf. ³⁶

Observation of scour conditions in natural materials has led to the following conclusions:

- o The laws of hydraulics governing the movement of loose materials are only distantly related to the better understood laws governing aged or virgin sediments.
- o Sediment in aged beds is composed of material of different sizes and, when the interstices are filled with smaller particles, the mass becomes more dense and stable and will be less subject to erosion.
- o The velocity required to scour an aged bed will be greater than that required to maintain the same particles in suspension.

One of the most commonly referenced representations of erosion and deposition criteria is a diagram developed by Hjulstrom and presented by Graf. 36 This diagram is shown in Figure E-1. The velocity term u is an average flow velocity in the immediate vicinity of the bed. Graf presumed that this average velocity is about 40 percent greater than the bottom velocity. The diagram indicates that loose fine sand is the easiest to erode and that an average velocity of approximately 20 cm/sec (0.66 ft/sec) would be required. Greater resistance to erosion in the small particle range is due to cohesion forces. For a bed of aged particles having a diameter of 0.002 mm (silt-clay range), an average water velocity of about 5.2 ft/sec would initiate erosion. To achieve the same resistance to flow as the cohesive clay, a particle size of about 15 mm (fine gravel) would be required. A serious uncertainty of this type of analysis is the degree of consolidation or aging which has occurred with the silt or clay. However, if the erosion resistance indicated by this diagram is accurate, then covering with sand (0.1-0.2 mm) may result in less stability than covering with a silt or clay.



Reprinted from Hydraulics of Sediment Transport by W. H. Graf by permission of McGraw-Hill Book Company

FIGURE E-1. EROSION-DEPOSITION CRITERIA FOR UNIFORM PARTICLES.

The fine-grained cover must have time to consolidate in place, however. This consolidation would be achievable if scouring currents at the spill site were rare (e.g. storm-induced) or seasonal. The cover could be applied at a time when nonscouring currents were anticipated for several months.

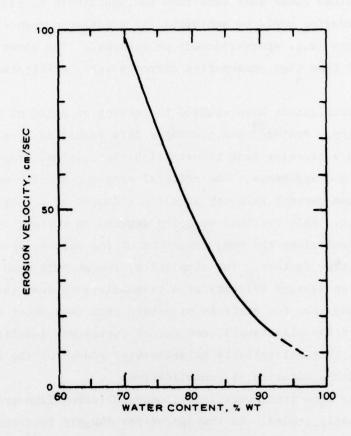
Few investigators have studied the effect of aging of clay deposits on erodibility. Postma ³⁷ has presented data resulting from experiments performed in a circular tank to establish the critical erosion velocity of fine-grained sediments. The critical erosion velocity was defined as the minimum current velocity at which sediment of a particular size began to move. This critical velocity depends on current velocity, tractive forces along the bed, roughness of the bottom, level of turbulence, and other factors. For simplicity, researchers usually describe the flow by an average velocity at a given distance near the bottom. Postma ³⁷ found that for particle diameters less than about 0.05 mm (upper end of the silt range), one set of curves was insufficient to describe the critical velocity relationship because of the effects of cohesion and the duration of consolidation.

Recently deposited, very loose, unconsolidated fine-grained matter is easily eroded. As the age of the deposit increases it will lose water and become more difficult to erode. Postma 37 has described the consolidation process thusly:

The process of consolidation is essentially the result of the expulsion of water from the interstices between soil grains under load. The water escapes through microscopic channels interconnecting the interstices. During the process the soil particles are displaced relative to one another and form a more closely packed sediment of greater density and lower water content. In sands and most clays these movements are irreversible. Consolidation proceeds very rapidly in sand, but very slowly in silts and clays; the rate depends on the type of clay mineral and the degree of flocculation.

As the water content decreases, the critical erosion velocity increases. Data discussed by Postma relating water content to critical erosion velocity are shown in Figure E-2 for a specific sediment.

Velocity measurements were taken 15 cm above the surface of the



MINERAL	%
QUARTZ	25
CHLORITE	15
FELDSPAR	5
EXPANDED ILLITE	25
KAOLINITE	15

Adapted from Estuaries, Publication No. 83, p 159 by H. Postma by permission of the American Association for the Advancement of Science, Copyright 1967

FIGURE E-2. EROSION VELOCITY VERSUS WATER CONTENT FOR A PARTICULAR SEDIMENT.

mud layer that had been allowed to settle from suspension. A water content of 91 percent corresponds to consolidation time of 3 hr, and 73 percent water content represents about 1 month's consolidation. Since the cohesive forces are largely dependent on the physical and mineralogical properties of the clays, the values shown are valid only for this particular clay. In addition, the critical erosion velocities found in these laboratory experiments may not be comparable to field values due to different velocity-turbulence relationships during erosion. Also, settling and consolidation in the experiments took place in spill water, whereas at sea, currents and wave motion will influence the consolidation process. It was also suggested by Postma 37 that since the natural water content of the sediment was about 40 percent compared to 73 and 91 percent in the experiments, the critical erosion velocity of the well-consolidated material might be considerably greater than 100 cm/sec and might approximate that for pebbles.

Partheniades 38 has conducted flume experiments to study the erosion and deposition of cohesive sediments. Two different conditions of the same sediment were tested. The first was natural material at field moisture and the second was a flocculated loose bed formed by deposition after the original bed had been placed in suspension. The composition of the sediment was 60 percent clay, 40 percent silt, and a very small amount of fine sand. The following conclusions were drawn as a result of the study:

- a. Although the macroscopic shear strength of the bed at field moisture was approximately 100 times as great as that of the flocculated bed, the minimum velocity at which scouring first occurred was approximately the same for both beds. The average rates of erosion were also of the same order of magnitude for the two beds.
- <u>b</u>. Erosion rates were independent of the concentration of suspended sediment.
- c. Erosion rates depended strongly on the average shear stress increasing very rapidly after a critical value of shear stress had been exceeded.
- d. There exists a limiting velocity above which all the eroded clay stayed in suspension and below which practically all sus-

pended clay was deposited. The limiting velocity occurred at about 0.5 ft/sec for this sediment and was slightly lower than the minimum scouring velocity.

e. A surface crust was formed, which showed a higher resistance to erosion than the clay. The crust was caused by cementation of silt and clay particles by iron oxides and by deposition of sand and silt that formed a continuous layer of relatively coarse particles.

A point raised by these researchers requires more consideration in light of the problem of covering spilled hazardous materials. The problem is to obtain an estimate of the time needed to achieve a certain degree of consolidation since the degree of consolidation has a direct effect on the critical erosion velocity of silt and clay. Very little information is available concerning this time/consolidation relationship. For the sediments in his experiments, Postma found a water content of 91 percent in 3 hr and 75 percent after 1 month. Under natural conditions the sediment had a water content of 40 percent, but the time needed to reach that value was not estimated.

Lambe and Whitman³⁹ have stated that the time required for a consolidation process is (1) directly proportional to the volume of water which must be squeezed out of the soil and (2) inversely proportional to how fast the water can flow through the soil. An expression relating these factors was presented by Lambe and Whitman as follows: ³⁹

$$t = \frac{mH^2}{k}$$
 (E-1)

where t = time required to complete some percentage of the consolidation process

m = compressibility of the mineral skeleton

H = thickness of the soil mass

k = permeability of the soil

This relation indicates that the consolidation time increases with increasing compressibility, decreases with increasing permeability, increases rapidly with increasing thickness of sediment, and is independent of magnitude of applied stress.

Although many of the factors affecting the time and degree of consolidation can be identified, very little field or laboratory data are available for consolidation of submerged sediment. It is apparent that sediment with a significant clay content will require consolidation time from a year to many hundreds of years, while coarse granular soil will become consolidated in a matter of minutes. This great degree of variability, depending primarily on sediment characteristics, makes it impossible at this time to make meaningful estimates of consolidation rates and then to estimate the effect of the time factor on erodibility. Considerable additional laboratory and field work will be required in this area.

A second point raised by the work of Partheniades³⁸ is that factors other than grain size and current velocity will affect the erosion of subaqueous sediments. Each of the following effects tends to decrease the erodibility of sediments:

- o Partheniades³⁸ has noted the formation of an iron oxide layer at the surface of the sediment deposit that caused cementation of silt and clay particles. Insoluble ferric iron is oxygenated at the surface of the deposit.
- o It was also noted by Partheniades 38 that hydraulic sorting of sediment can cause a continuous layer of relatively coarsegrained particles to form on the surface. This sand layer acts as a continuous plate and may cause a significant increase in the resistance to erosion. Application of this observation to covering is difficult, because the available methods for placing sand over an unconsolidated fine-grained cover would be too violent to produce a surficial sand layer. Sand grains would more likely mix with the fines.
- o Pratt et al. 35 have noted that tube-dwelling organisms inhabit organic sediments and thereby decrease erodibility by secreting cementing agents for formation of the tubes.
- o Graf³⁶ has cited several investigations by others which indicate that the erosion resistance of a sediment containing a distribution of particle sizes will be greater than that of a sediment containing particles of only one size.

This discussion of scour and resuspension has shown the complexity of this area of inquiry and that the subject defies generalizations. However, for the guidance of those who must base important spill

response decisions on the available information, Table 5-2 is presented in the main text as a qualitative guide to erosion and resuspension potential.

APPENDIX F: SPECIAL PURPOSE COMMERCIAL CLAYS - COST AND AVAILABILITY

F.1 KAOLINITES (KAOLIN)

Kaolin (often termed china clay) is primarily mined in Georgia, Alabama, and Mississippi and costs approximately \$22 per ton (about 1 cu yd) in dry bulk quantities. Shipping will add another \$20 to \$40 to the per ton cost, with highest costs for shipment to the west coast. Bulk quantities are readily available. Fastest shipment would be by truck.

F.2 BENTONITE

Bentonite (the Wyoming or expanding variety) comes in both regular grades and salt-resistant grades. Regular grades will be rendered ineffective in salt water. It is often used in the sealing of lagoons, ponds, and similar bodies of water. Bentonite may be surface applied and will sink to the bottom of a water body where it can expand and form an impervious covering. Generally speaking, large quantities of expanding bentonite materials are only available from the mines located in Wyoming and South Dakota and 7 to 10 days should be allowed for delivery by truck to the east coast, somewhat less to the west coast. Carload lots will run in excess of \$100 per ton (about 1 cu yd) with delivery costs additional (about \$60 per ton to east coast shipped by rail). Bentonite's proven sealing capabilities (it will expand in place) make its use in covering feasible, despite its cost. Its adsorptive properties are high, further enhancing its desirability. (In this sense, it can be considered an active material.) This combination of sealing and adsorption may make it the most attractive of the special purpose clays.

F.3 FULLER'S EARTH

Fuller's earth (similar in many respects to nonexpanding or

southern bentonite) is commonly used in animal litter, oil sorbent materials, and similar applications. It is available from mines in the southeastern United States in bulk quantities and can be prepared for shipment in less than a day. Total cost, including delivery, would run perhaps \$60 to \$80 per ton (about 1 cu yd). It is not especially adsorptive.

F.4 BALL CLAY

Ball clay (similar to kaolin), used in refractories, floor and wall tile, and similar applications, is generally mined in the area of Tennessee, Kentucky, and Mississippi, with lesser amounts taken in Maryland, Texas, and California. It is produced in large quantities and is available for shipment on short notice. Prices FOB plant run about \$40 to \$50 per cubic yard for processed ball clay. Transportation costs could add another \$30 to \$80 depending on distance with highest costs to the west coast. It could be at a spill site in the northeastern U. S. in about 12 to 20 days using rail transportation. Some synonyms for ball clay are ceramic, refractory, foundry, pottery, and sanitary clays.

F.5 FIRE CLAY

Fire clay (also similar to kaolin) is used in the production of refractories. Fire clay is produced in scattered locations throughout the U. S. including California, Pennsylvania, New Jersey, Alabama, and other states and is available in bulk quantities. Prices FOB plant for processed fire clay run \$200 to \$300 per cubic yard. Transportation to the spill site will be extra. Fire clay may also be known as refractory clay or foundry clay.

F.6 MISCELLANEOUS CLAYS

These clays are actually clays and shales whose commercial usage does not fit any of the other categories of clay. These clays together

constitute a significant percentage of U. S. production, and deposits are located throughout the United States. Reserves are great and the material has obvious usefulness as inert cover. Availability will be subject to local conditions, as deposits near major metropolitan areas may be few in number. Average costs for unprocessed clay should be in the vicinity of \$2.00 to \$3.00 per ton plus transportation to the spill site.

F.7 DIATOMACEOUS EARTH

Bulk quantities of diatomaceous earth are available from west coast processors. The material, commonly used in filtering applications, is available in 30- to 40-ton carload quantities on short notice. Costs will run about \$70 to \$120 per ton (about 1 cu yd) FOB plant. Shipping would be additional and would be in the vicinity of \$20 to \$40 per ton depending on distance from the mine. No inherent advantage over other fine-grained material is expected.